Dynamic Multi-Modality Fused Imaging, Analysis, Computer Aided Diagnosis System
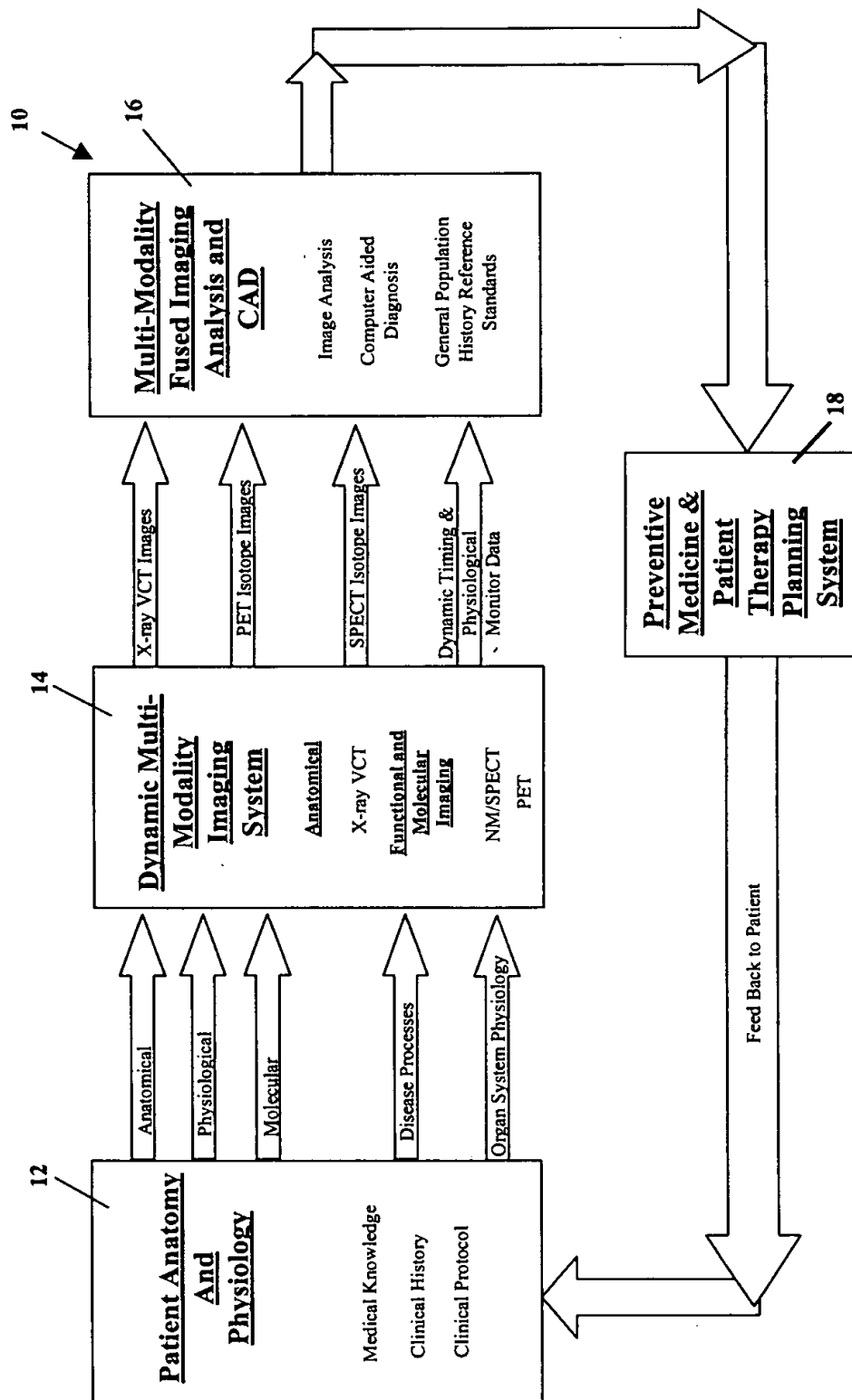
10

12

Patient Anatomy And Physiology

Medical Knowledge

Clinical History

Clinical Protocol

→ Anatomical
→ Physiological
→ Molecular
→ Disease Processes
→ Organ System Physiology

14

Dynamic Multi-Modality Imaging System

Anatomical

X-ray VCT

Functional and Molecular Imaging

NM/SPECT

PET

→ X-ray VCT Images
→ PET Isotope Images
→ SPECT Isotope Images
→ Dynamic Timing & Physiological Monitor Data

16

Multi-Modality Fused Imaging Analysis and CAD

Image Analysis

Computer Aided Diagnosis

General Population History Reference Standards

18

Preventive Medicine & Patient Therapy Planning System

Feed Back to Patient

Figure 1

Multi-Modality Imaging System with Common Focused 2D Curved Detector
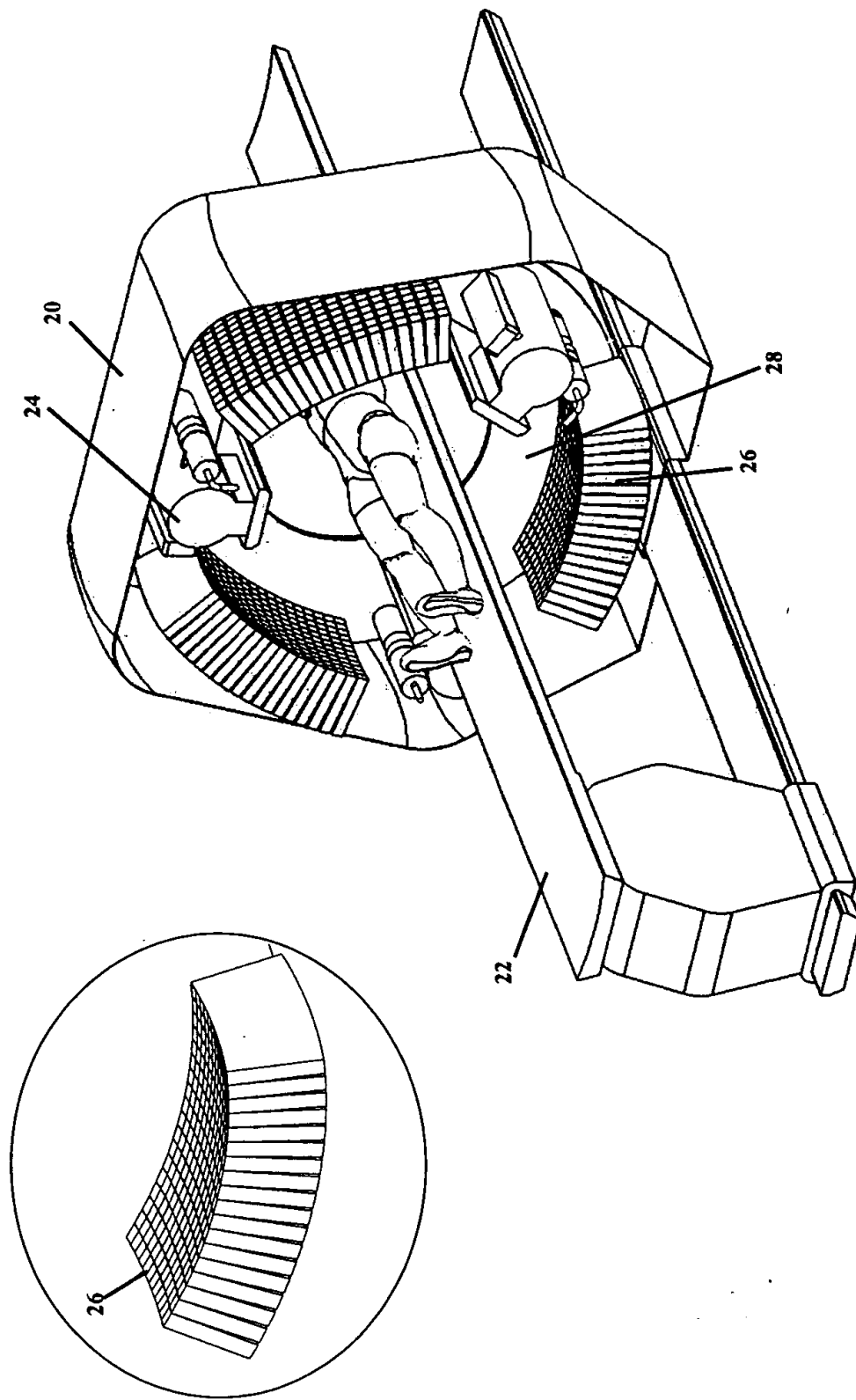
Figure 2

Overall Multi-Modality Imaging System Block Diagram

Figure 3
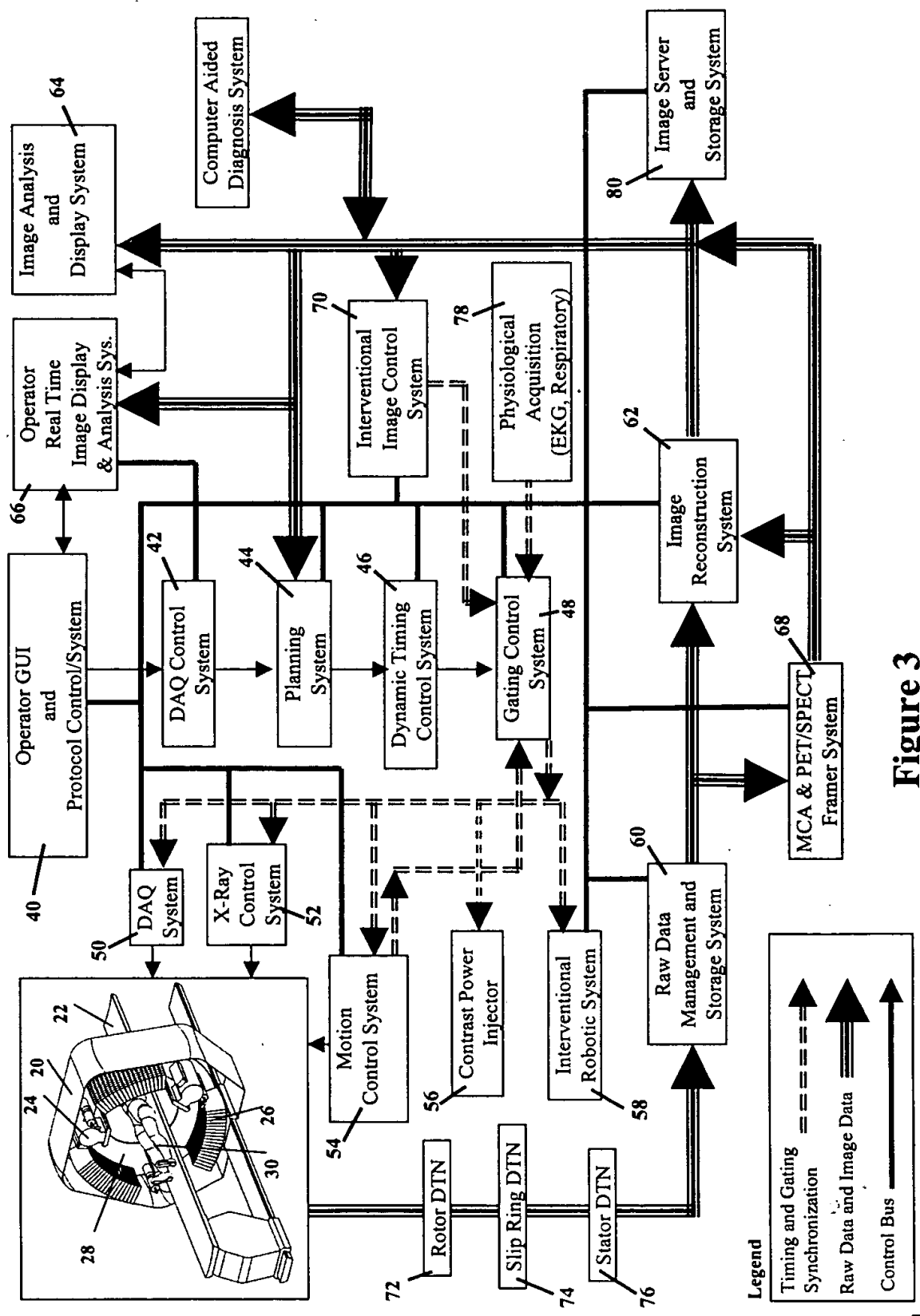
Legend

Timing and Gating Synchronization

Raw Data and Image Data

Control Bus

X-ray & Focused 2D Curved Detector Arrangement
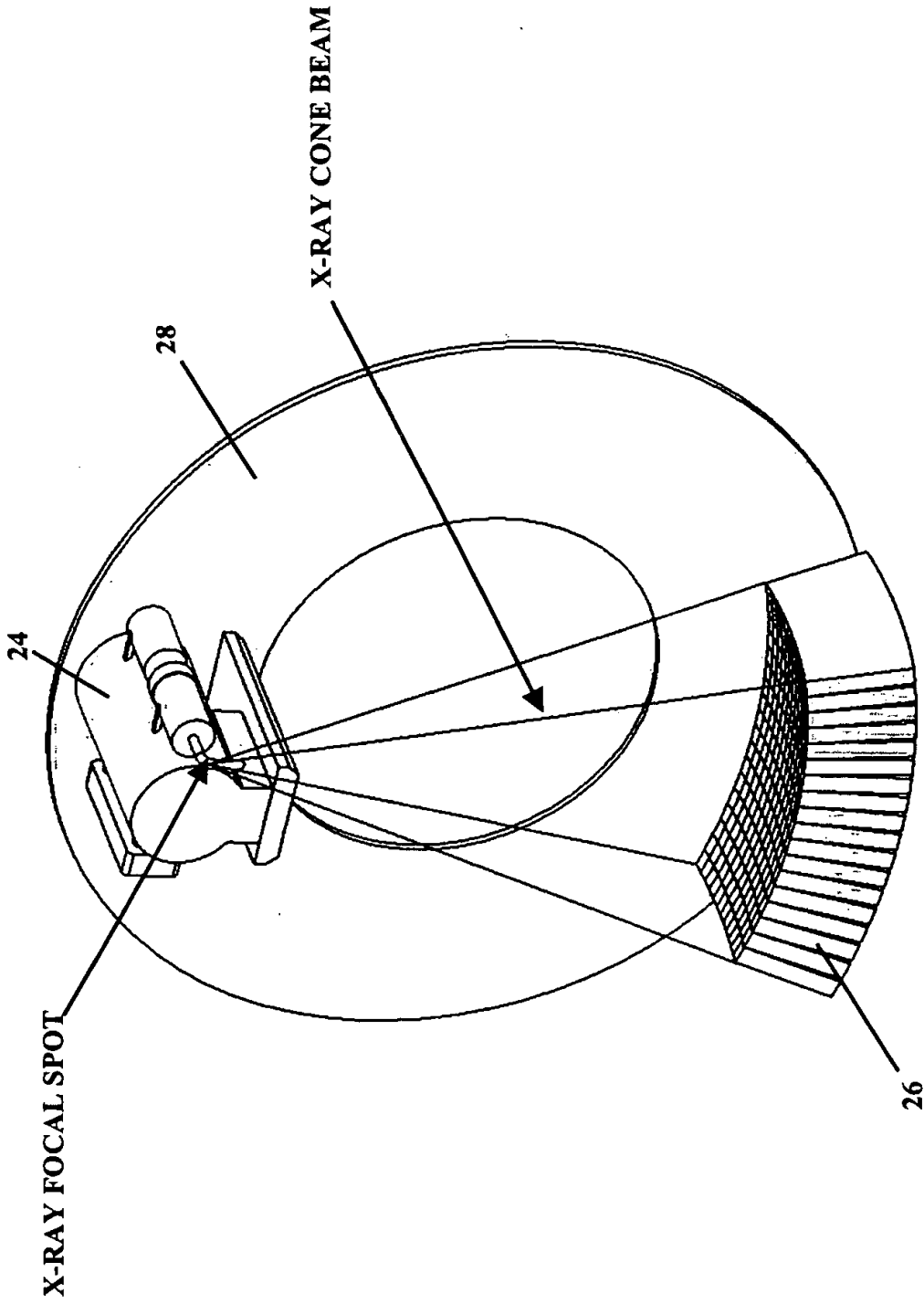
X-RAY FOCAL SPOT

X-RAY CONE BEAM

28

24

26

Figure 4

Cone Beam Source Collimation & Cone Beam Shaped Filter

X-ray Intensity after Attenuation by Cone Beam Shaped Filter

Fan angle across shaped filter

FIG. 5b

Intensity after Attenuation by Shaped Filter and Patient

X-ray Dose and X-ray Intensity Normalized Across Patient Projection

Fan angle across patient and shaped filter

FIG. 5d

82

26

Z

FIG. 5a

82

84

30

26

X

Shaped Compensation Filter Exploded View

82

84

Z

Cone Beam Source Collimation

X

82

84

Exploded View

FIG. 5c
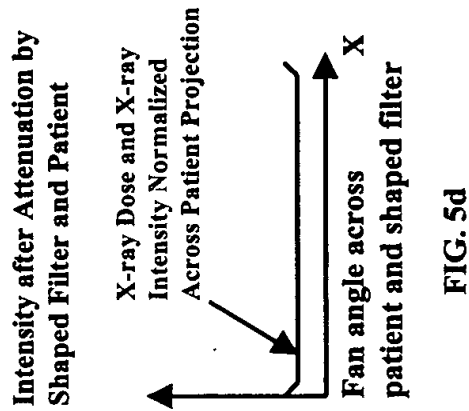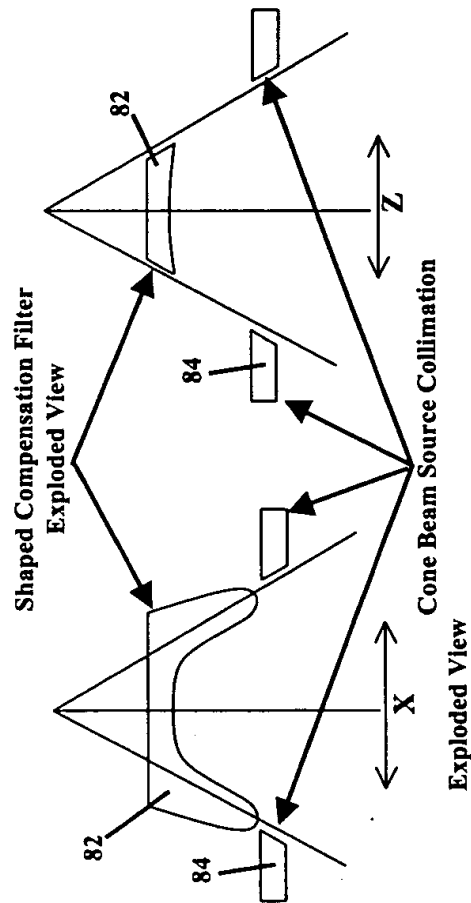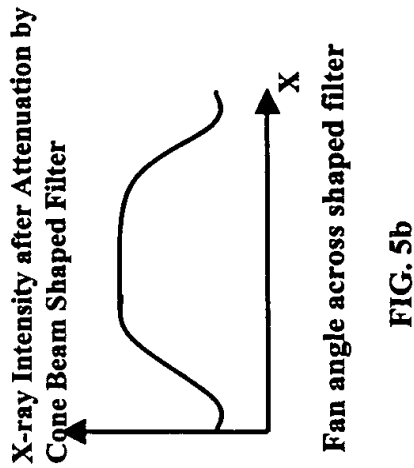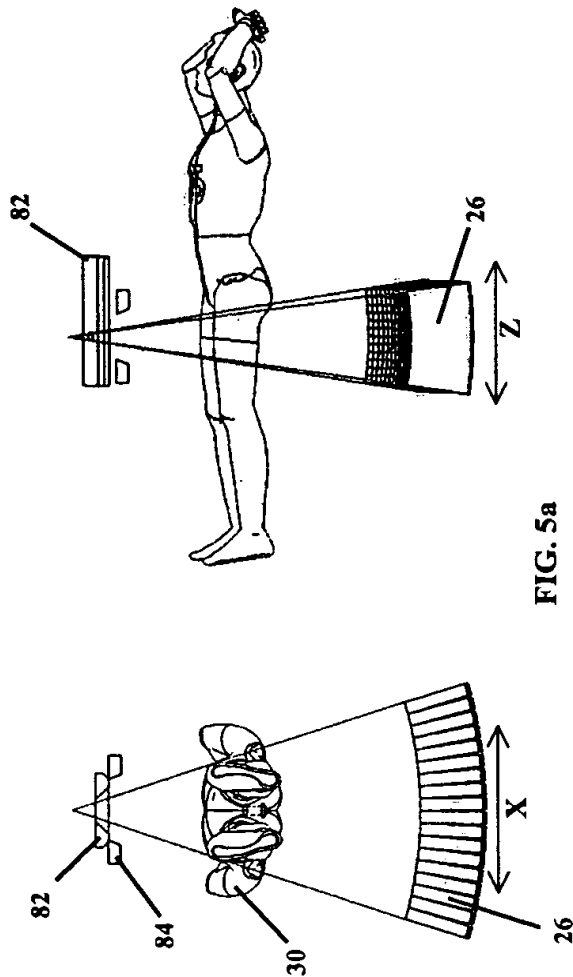
Figure 5

X-ray Cone Beam Focal Spot – Curved Detector Optics
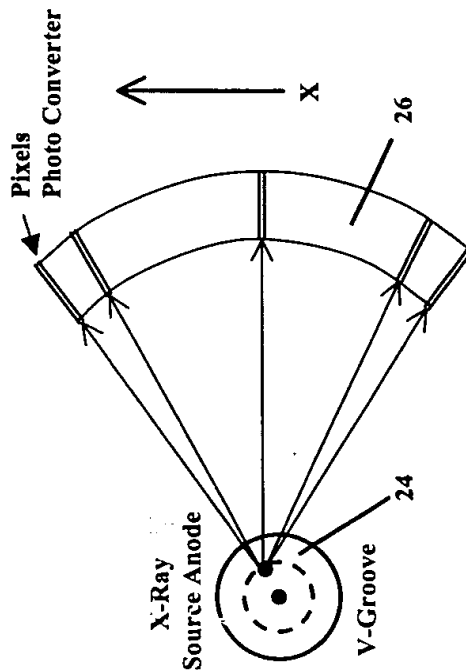
Focal spot from V-groove Type Anode has similar spot size appearance

Position of Cone Beam with respect to Z axis

V-groove X-ray Anode

20°

+Z max

-Z max

24

Spatial Impulse Response

+Z max

0 Z

-Z max

Spatial Resolution

FIG. 6b

Position of Cone Beam with respect to Z axis

Traditional Slant X-ray Anode

+Z max

-Z max

Spatial Impulse Response

+Z max

0 Z

-Z max

Spatial Resolution

FIG. 6c

Curved Detector to reduce spatial resolution loss and Best Conversion efficiency of X-ray

Pixels
Photo Converter

26

Z

X-Ray Source Anode

V-Groove

24

Pixels
Photo Converter
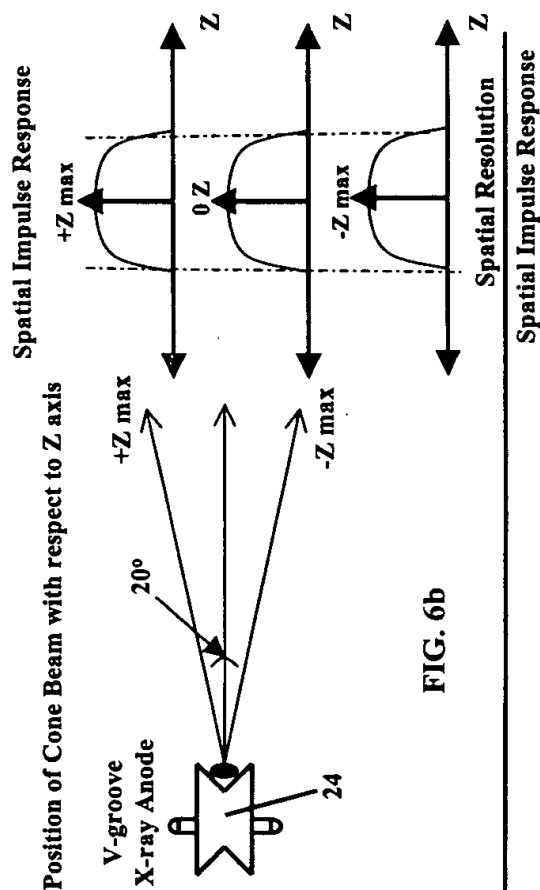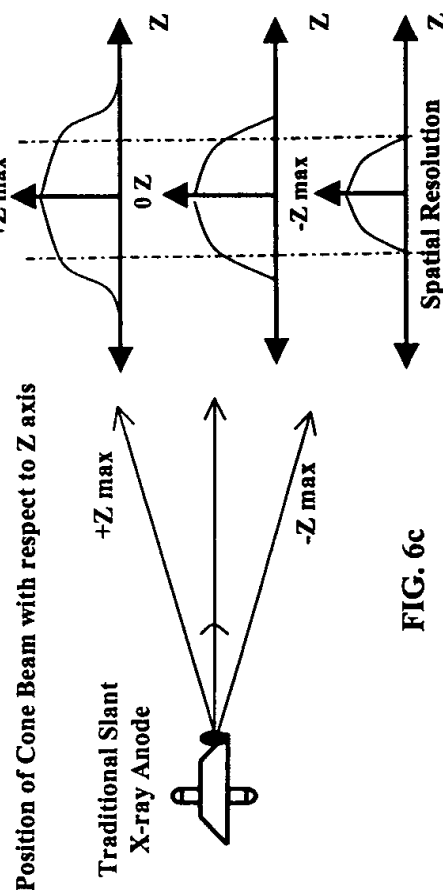
26

X

X-Ray Source Anode

V-Groove

24

FIG. 6a

Figure 6

2 Dimensional Focal Spot Dithering for Improved Cone Beam Spatial Resolution

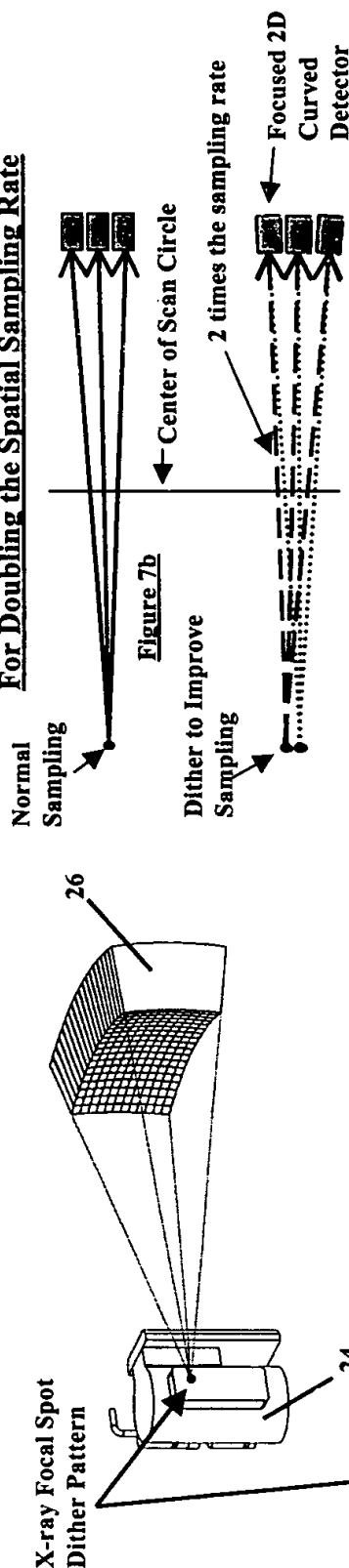## X-ray Focal Spot Geometric Dithering For Doubling the Spatial Sampling Rate

Focused 2D Curved Detector

2 times the sampling rate

Center of Scan Circle

Figure 7b

Normal Sampling

Dither to Improve Sampling

Figure 7c

Spatial Resolution comparison between Single Sampling and 2X Dither Sampling

System Frequency Response

2X Dither Nyquist Sample Freq.

2X Dither Spatial Response

Normal Nyquist Sample Freq. & aliased optical response

Spatial Frequency Response

LP/cm

1.0 0.8 0.6 0.4 0.2 0.0

0 10 20 30 40 50

Figure 7f

X-ray Focal Spot Dither Pattern

26

24

Figure 7a

2D X-ray Focal Spot Dither Pattern for 3D Cone Beam VCT

Z-axis Dither

X-axis Dither

Figure 7d

Optical System Frequency Response

X-ray Optical System Response before Sampling

Spatial Frequency Response

LP/cm

1.0 0.8 0.6 0.4 0.2 0.0

0 10 20 30 40 50

Figure 7e

Figure 7

Focused 2D Curved Detector Module

Focused Curved Detector Module

FIG. 8a

96 — Signal Processor and Digital Converter

94 — Photo Converter

2D Focused Collimator

90

92

View Showing Focused 2D Anti-scatter Collimation with 2D Focused Pixels

FIG. 8c

90

96

94

92

92

FIG. 8d

X-ray Focal Spot

90

96

94

92

FIG. 8b

Figure 8

Focused 2D Area Detector with Adaptive Shaped X-Ray Optical Response

FIG. 9a

FIG. 9b

Detector Pixel

Impulse Response of Shaped Detector Pixel

A

B

Pixel Weighting

1	1	1
1	1	1
1	1	1

A

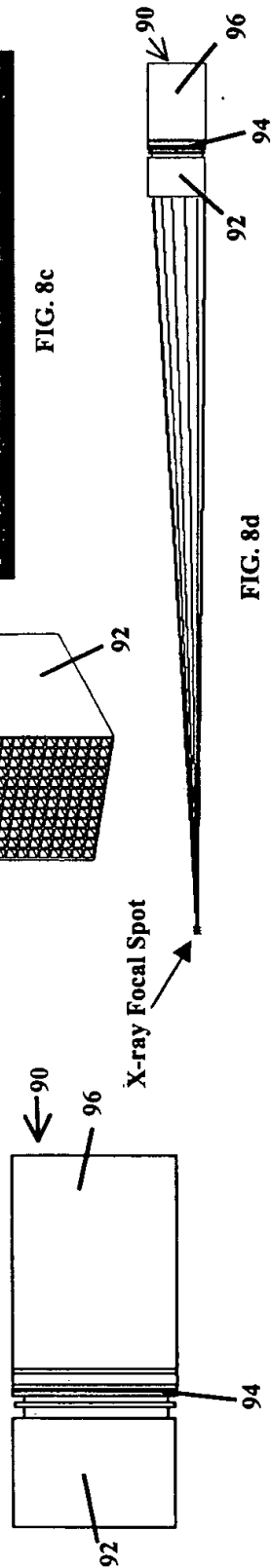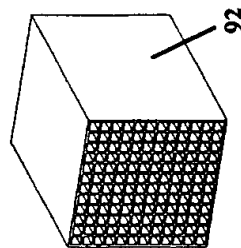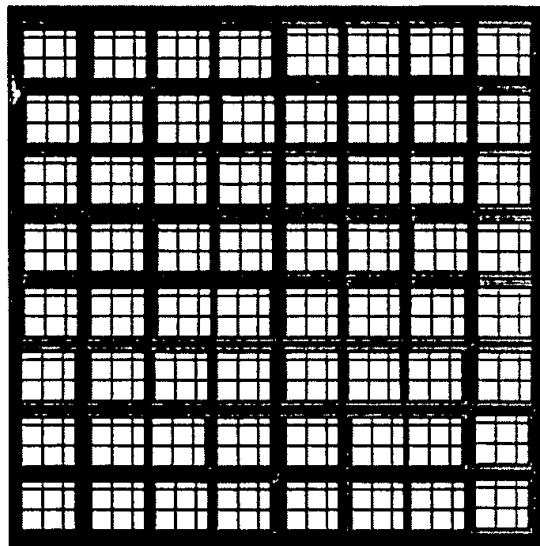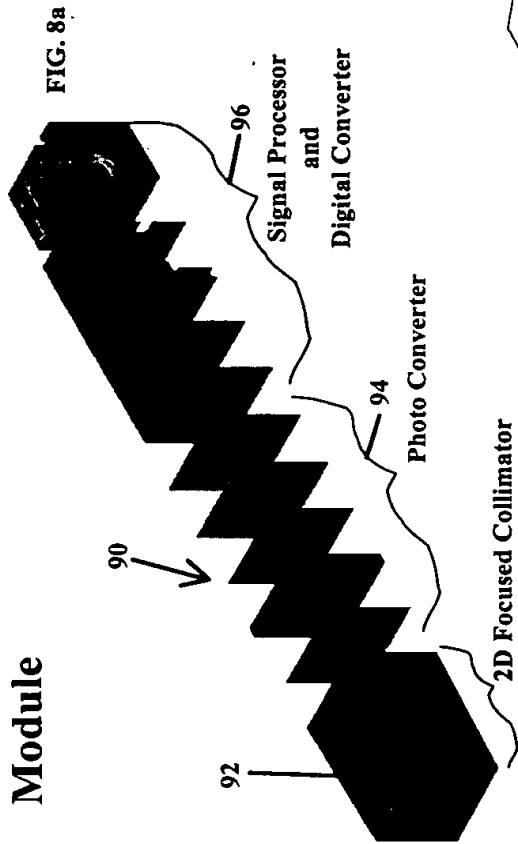|		
.2	44	.2
44	1	44
.2	44	.2

B

FIG. 9f

FIG. 9e

FIG. 9d

Impulse Response Shaping from Rectangular to Variable guassian Roll-off Function. Shaping may be Fixed or Controlled

FIG. 9c

Figure 9

Multi-Modality XGA Detector Module
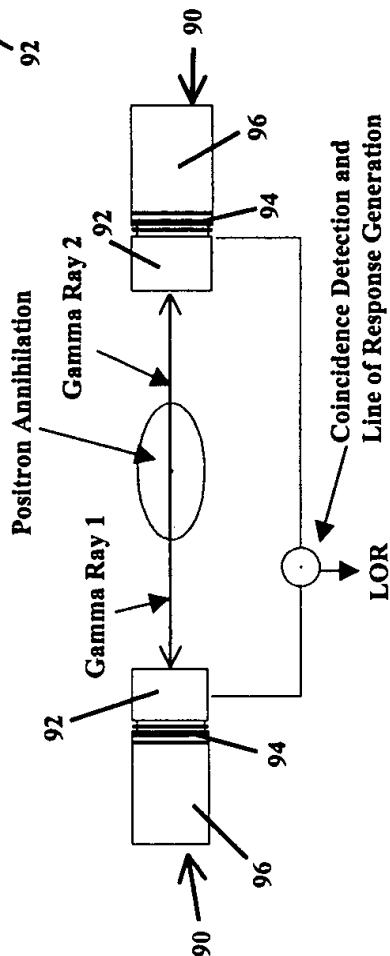
X-Ray Mode

FIG. 10a

X-ray Focal Spot

90

96

94

92

PET Mode

FIG. 10b

Positron Annihilation

Gamma Ray 2

Gamma Ray 1

90

96

94

92

92

94

96

90

Coincidence Detection and
Line of Response Generation

LOR

NM/SPECT Mode

FIG. 10c

98

98

100

102
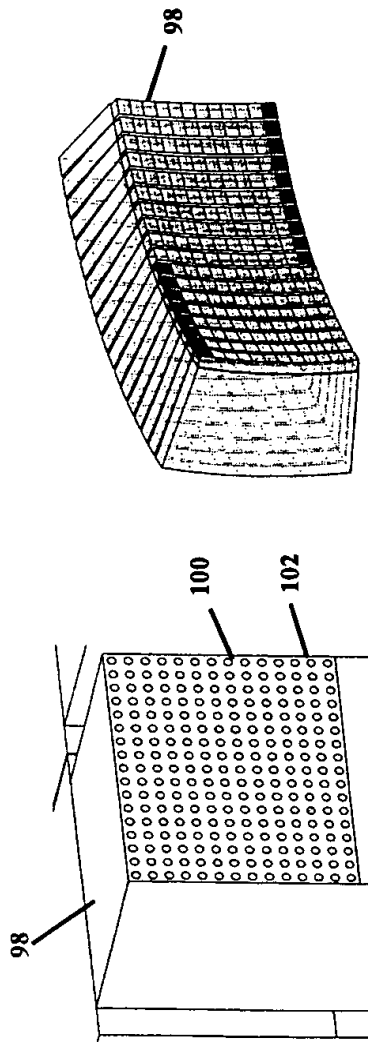
Figure 10

Detector Module Multi-Modality Collimation

X-RAY MODE

Collimation Section Focused for X-ray Scatter Rejection

FIG. 11a

92

X-ray Focal Spot

NM/SPECT MODE

Collimation Section as Above for Gamma Camera Collimation at Lower Energies

FIG. 11b

92

Radiation From SPECT Isotopes

Focus Vertex
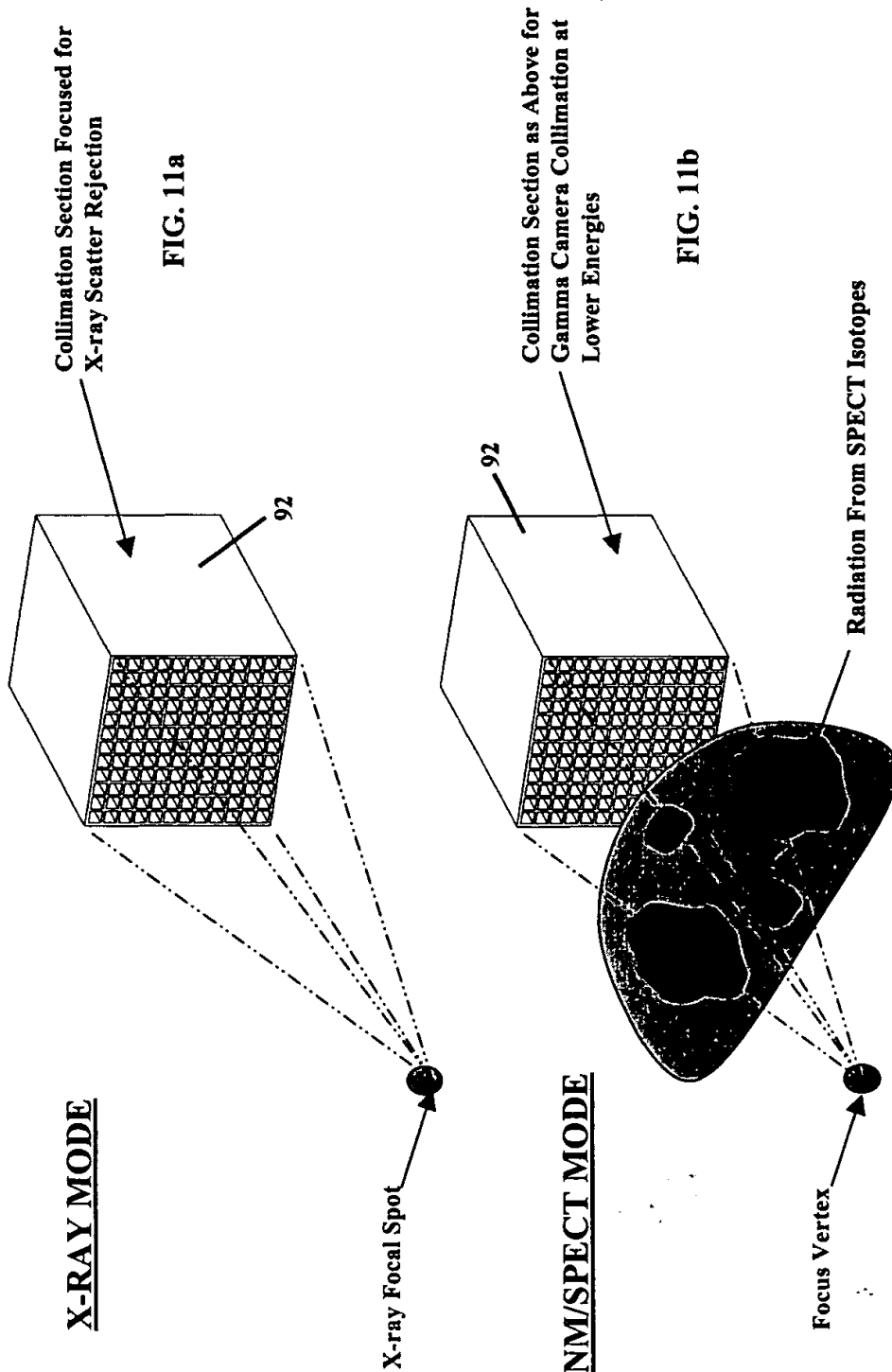
Figure 11

XGA Detector Module Signal Processing

Synchronous Sampling

X-ray Mode

X-Ray → Photo Converter (110) → Pre Amp (112) → Signal Processing & Integration (114) → A/D (118) → Sampled X-ray Intensity

Synchronous Sampling (116) → Signal Processing & Integration

Gating Control (48) ← Synchronous Sampling

Rotate Position
Traverse Position
Physiological Gating (EKG)
→ Gating Control

FIG. 12a

Asynchronous Sampling

NM/SPECT Mode

Gamma Ray → Photo Converter (110) → Pre Amp (112) → Signal Processing and Integration (114) → A/D (118) → Sample Energy

Signal Processing and Integration → CFD (120) → Threshold Level Trigger (122)

Integrate Control → Threshold Level Trigger

Threshold Level Trigger → Time Stamping (124) → Sample Time

FIG. 12b

Coincidence Detection

PET Mode

Sample Time 1 → Digital Coincidence (126) → LOR Generation (128) → LOR of Response

Sample Time 2 → Digital Coincidence

180 Degree Opposed Detector Detecting Coincident 511 KEV Gamma Ray

90, 92, 94, 96

FIG. 12c

Figure 12

System with Optional PET Anti-Scatter Baffle
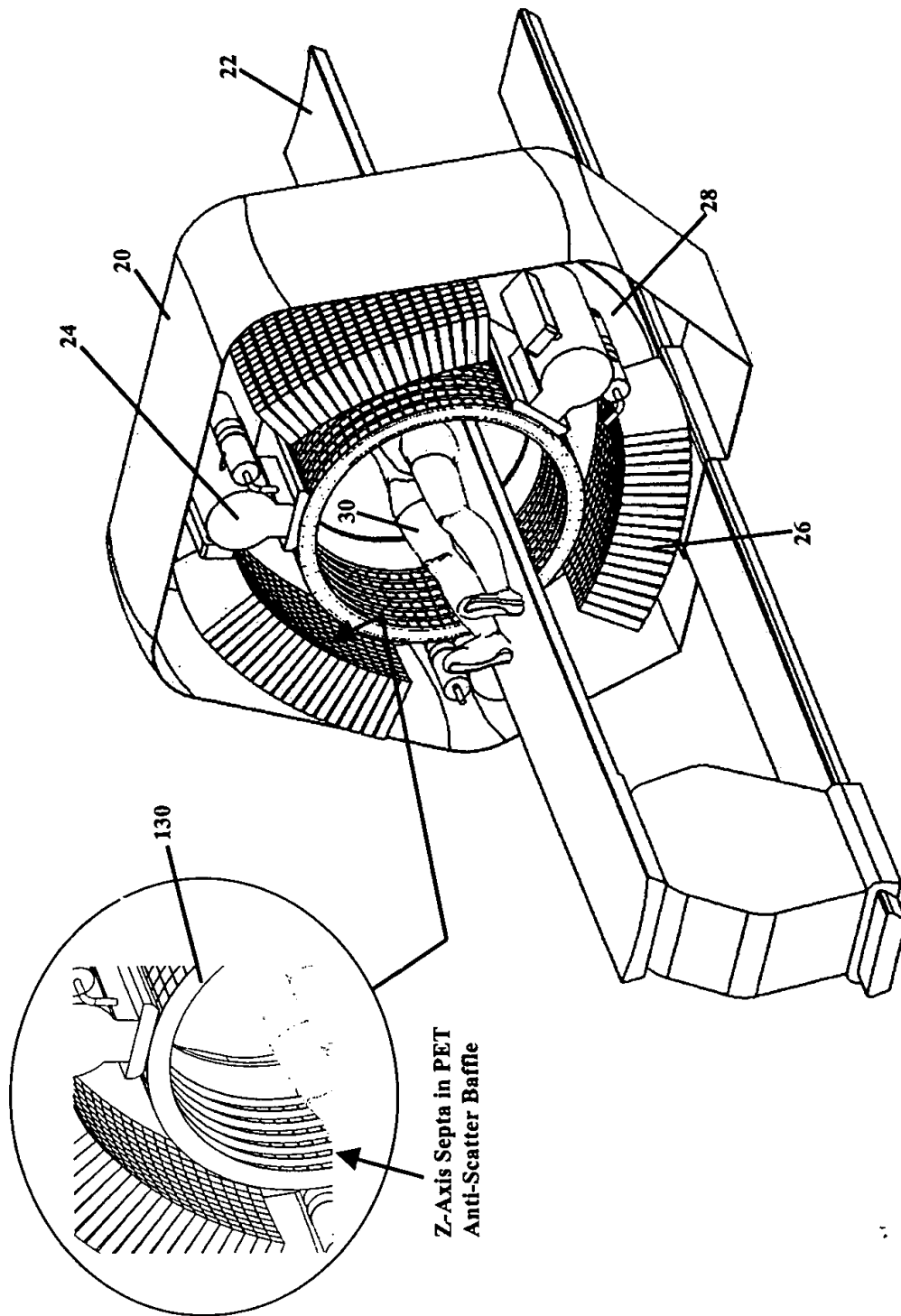
Z-Axis Septa in PET Anti-Scatter Baffle

Figure 13

PET – Anti-Scatter Baffle SEPTA

24

130

28

26

130

Rejection of Out of
Field of View Events
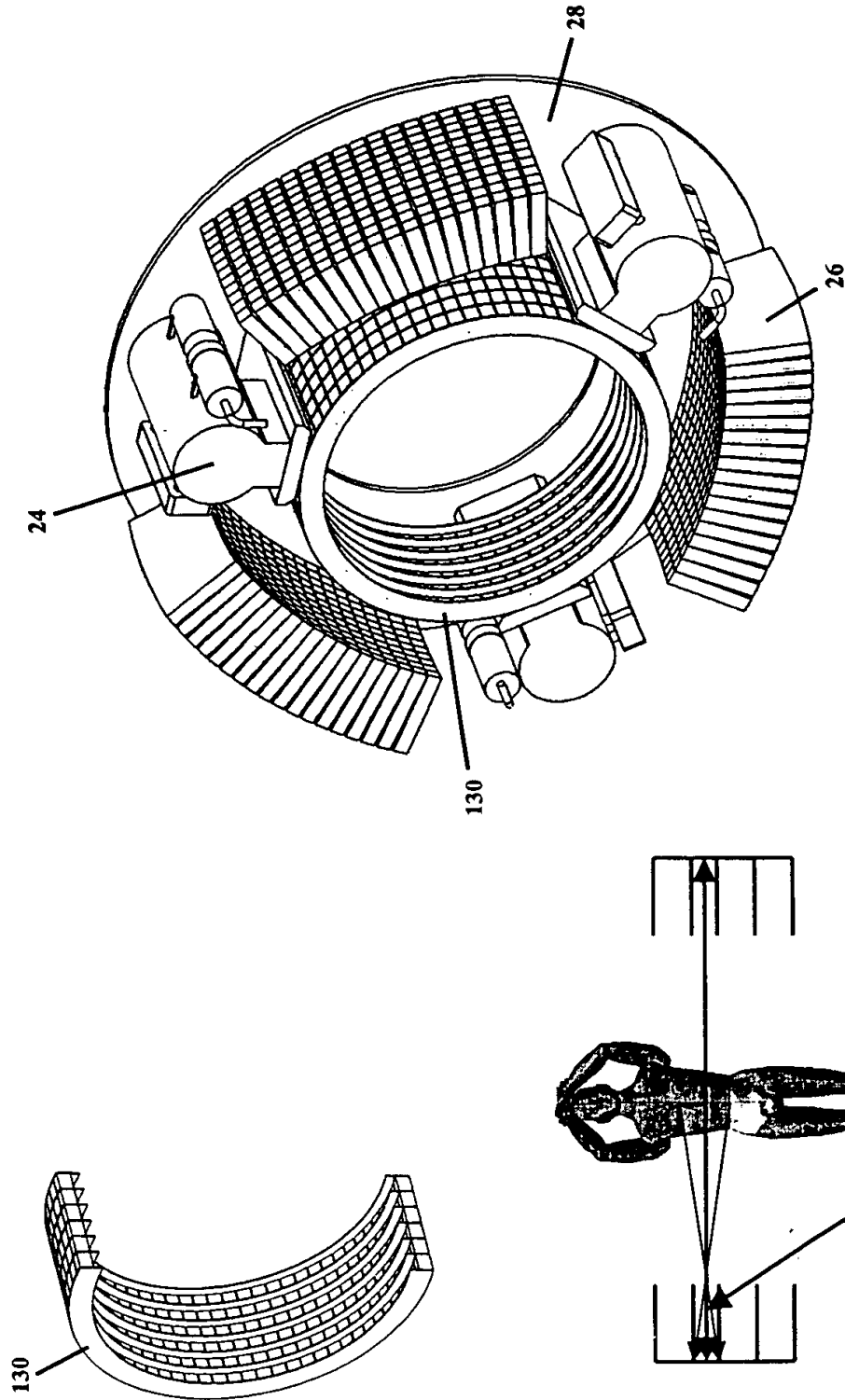
Z-Axis 3D Mode Scatter Reduction Baffles
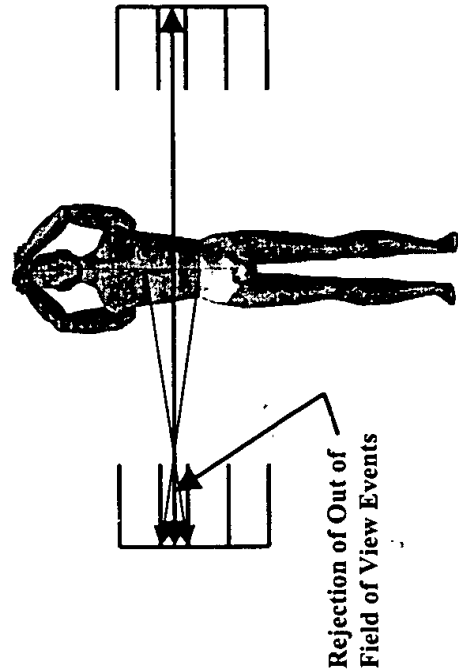
Figure 14

System With Cone Beam Focused NM/SPECT Collimation
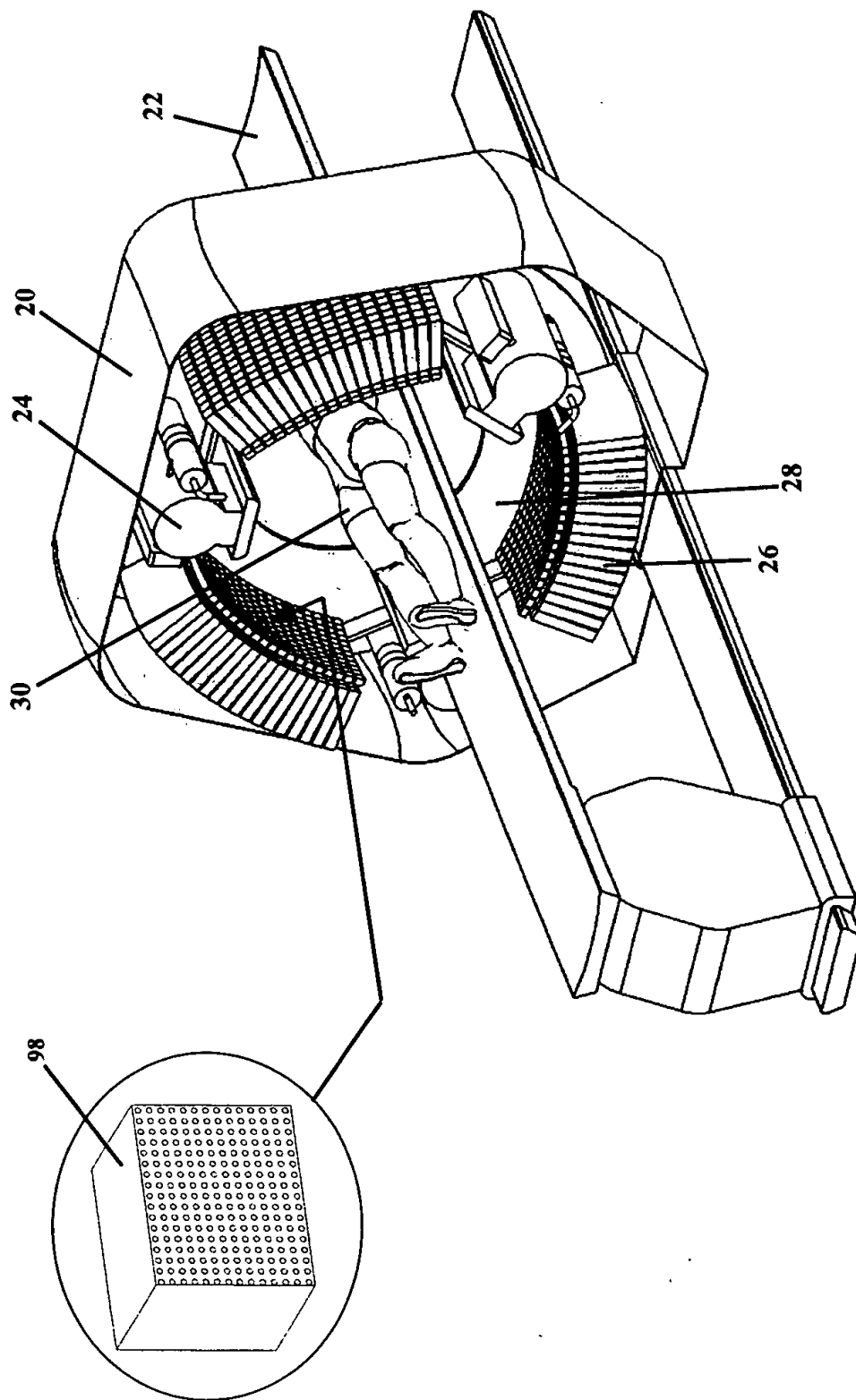
Figure 15

NM/SPECT Mode with Collimation Ring

Collimator Apertures and SEPTA
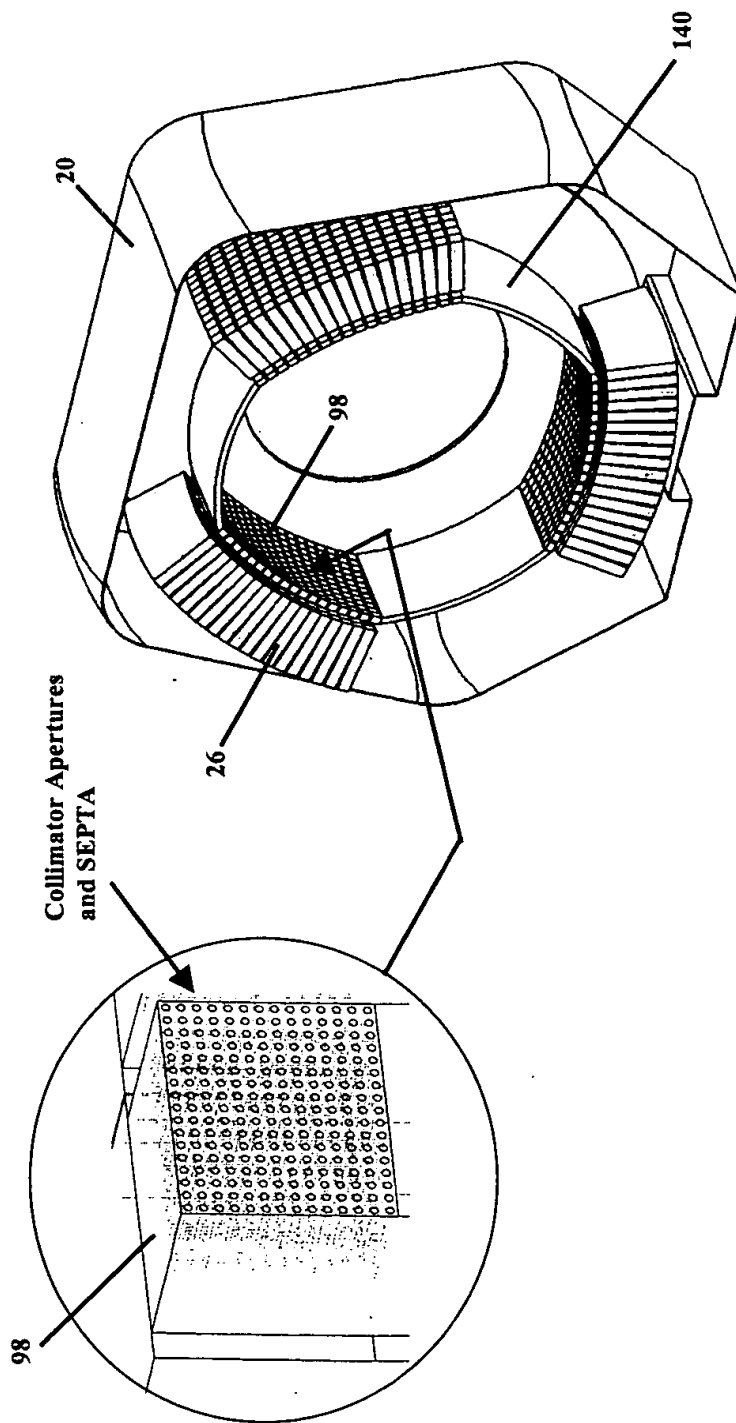
Figure 16

Cone Beam NM/SPECT LEHR Collimation and Focused 2D Curved Detector Array

Cone Beam
SPECT Collimation
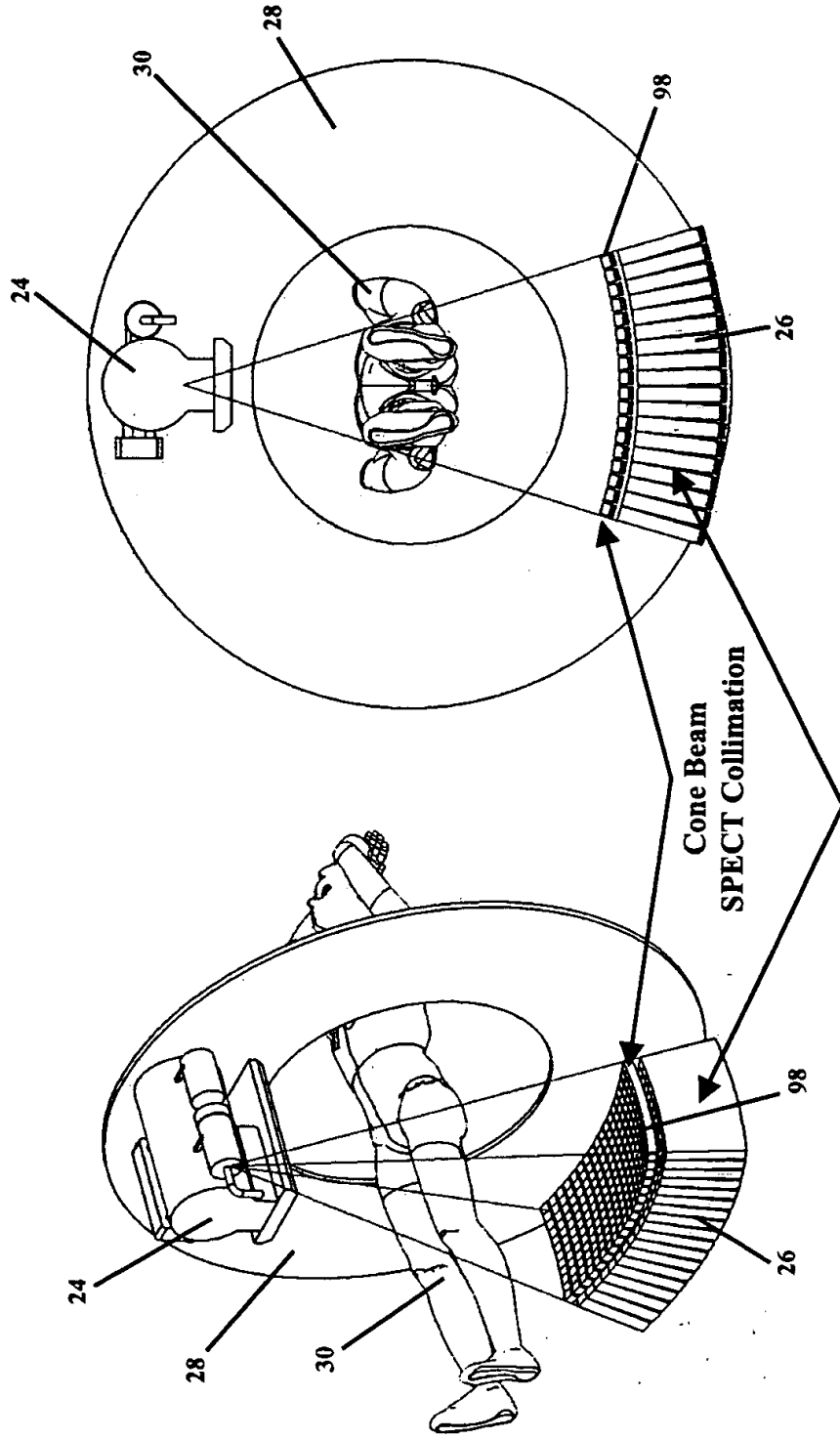
X-ray Gamma Ray Area Detector. [XGA] Detector Which
is Focused at Point Where X-ray Focal Spot is.

Figure 17

Multi-Isotope Scanning

511 KEV Photo Peak

PET

140.5 KEV Photo Peak
Imaging Energy Window

SPECT

Tc-99m
Photo Peak

High Scatter
Window #2

Compton Down
Scatter

Low Scatter
Window #1

511 KEV

140.5 KEV

MCA (Multi – Channel Analyzer)

- Scatter Correction and 511 KEV Photo Peak Suppression for SPECT Imaging

- NM/SPECT Detector Must Function with 511 KEV Isotope Present for Multi-Isotope Imaging

Figure 18

X-Ray Detector Scatter Rejection with Focused 2D Curved Collimation

Scatter
Rejection of
2D Focused
Curved Detector
Collimation

26

92

Rejection of
Scatter Signal

Patient

90

92

Direct
Signal

Scatter
Signal

X-Ray

24

Also used for NM Gamma and SPECT Collimation

Acceptance Angle $(\alpha) = \tan^{-1} (D/L)$

L

D
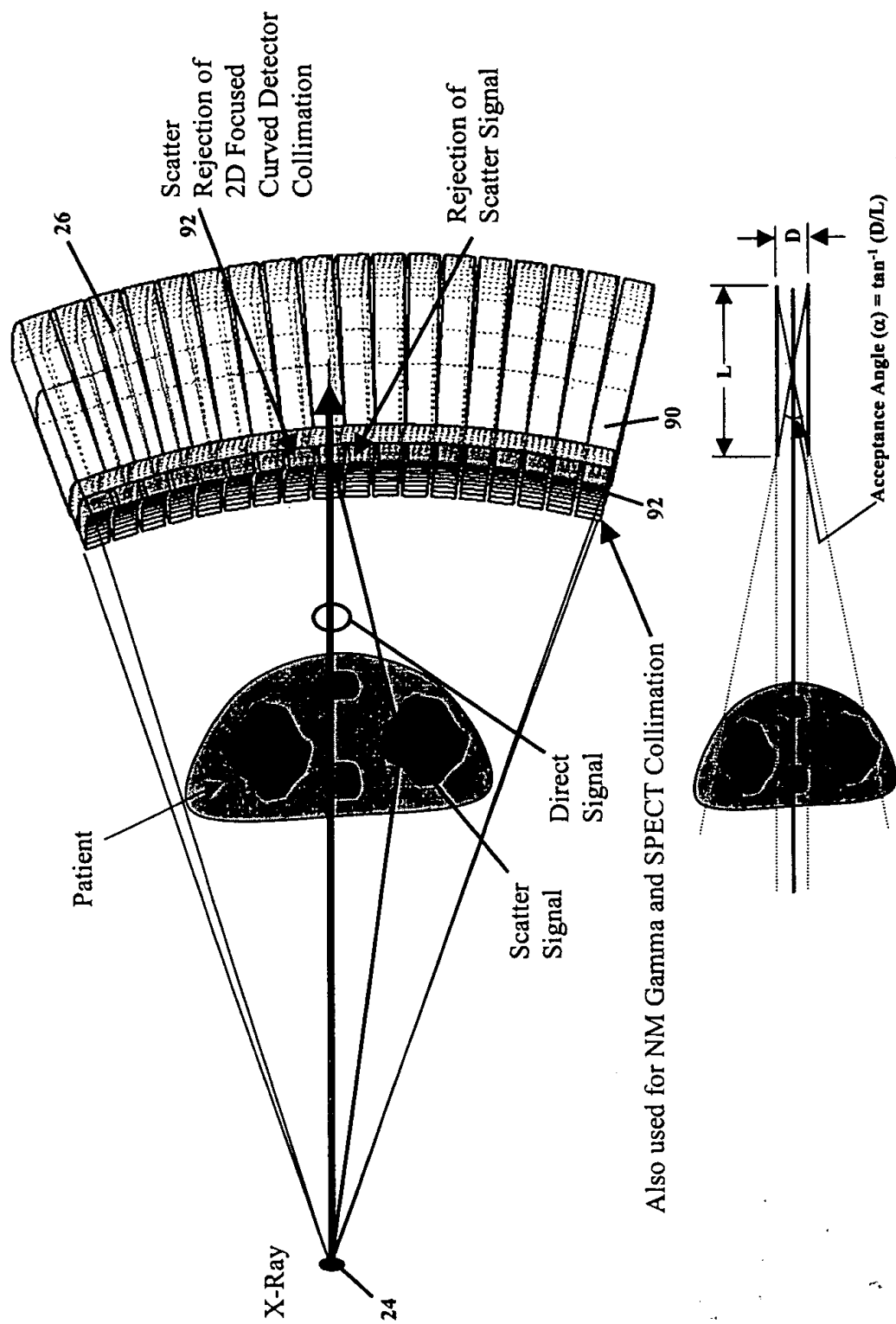
Figure 19

Sequencing of X-ray Sources for Adaptive Scatter Correction

Scatter Signature From each View or
Sub Sampled Views
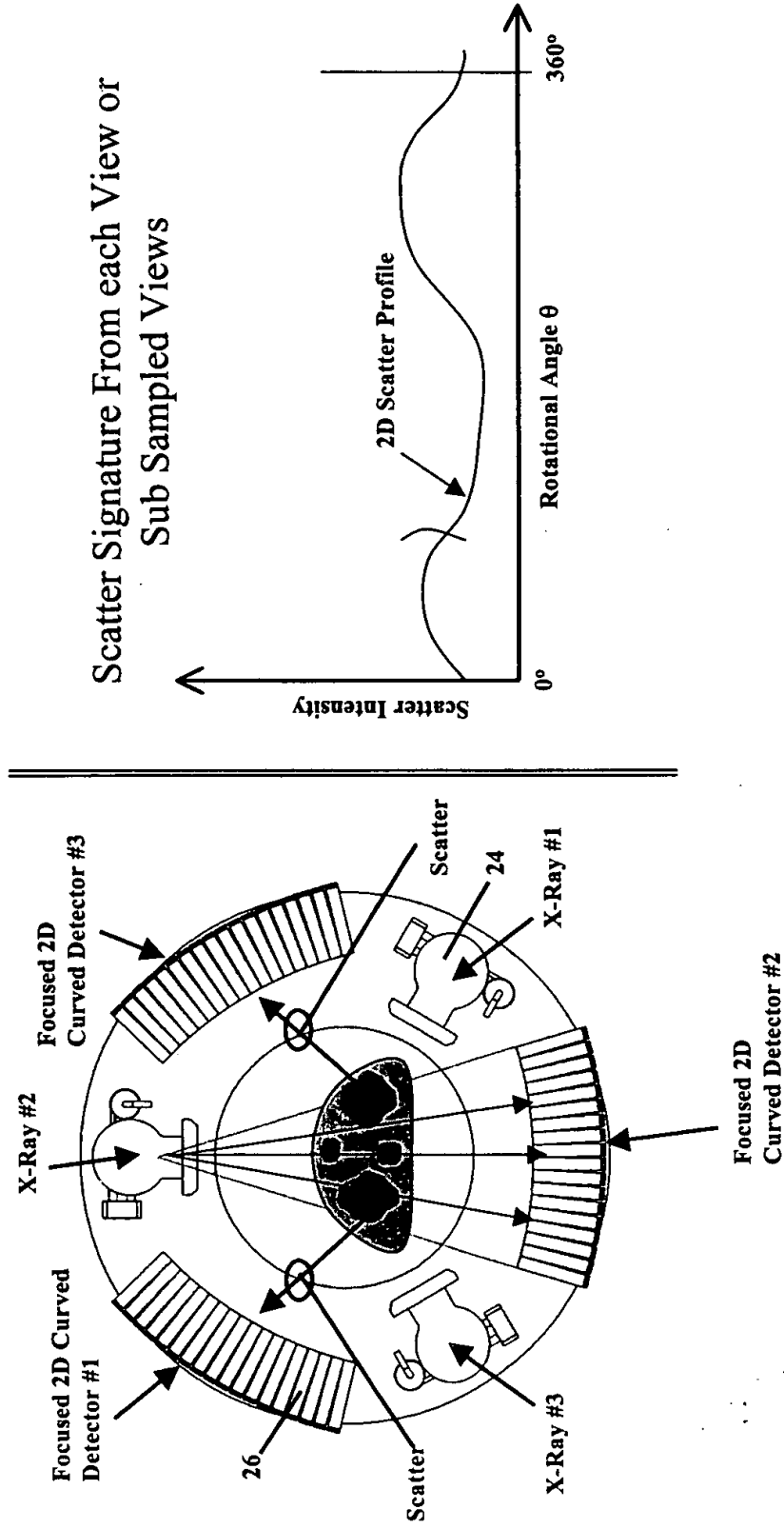
Figure 20

Modulation and Demodulation for Scatter Correction with Multiple Sources

Modulation F #1

Grid Modulation

Detector #2

Modulation F #3

Grid Modulation

X-Ray #3

Scattered Signal From #3

Scattered Signal from #2

Demodulated

Demodulation Signal from Detector #1

FIG. 21c

F F F
#3 #1 #2

FIG. 21b

X-Ray #1

24

Detector #3

Modulation F #2

Grid Modulation

X-Ray #2

Scattered Signal from #2

26

Detector #1

Direct Signal

PreAmp

Direct Demod

LPF

Demodulation Signal #1

FIG. 21a

Figure 21

System Level Diagram of Modulation and Demodulation For Multiple Sources for VCT

Master Modulation Signal F #1 — 164

Modulation Signal — 160

Grid Control — 162

Detector #2

X-Ray #3

Scattered Signal From #3

Demodulated

Demodulation Signal from Detector #1

X-Ray #1

24

26

Detector #1

PreAmp — 168

Demodulation — 166

Detector #3

X-Ray #2

Scattered Signal from #2

F #2

F #1

F #3
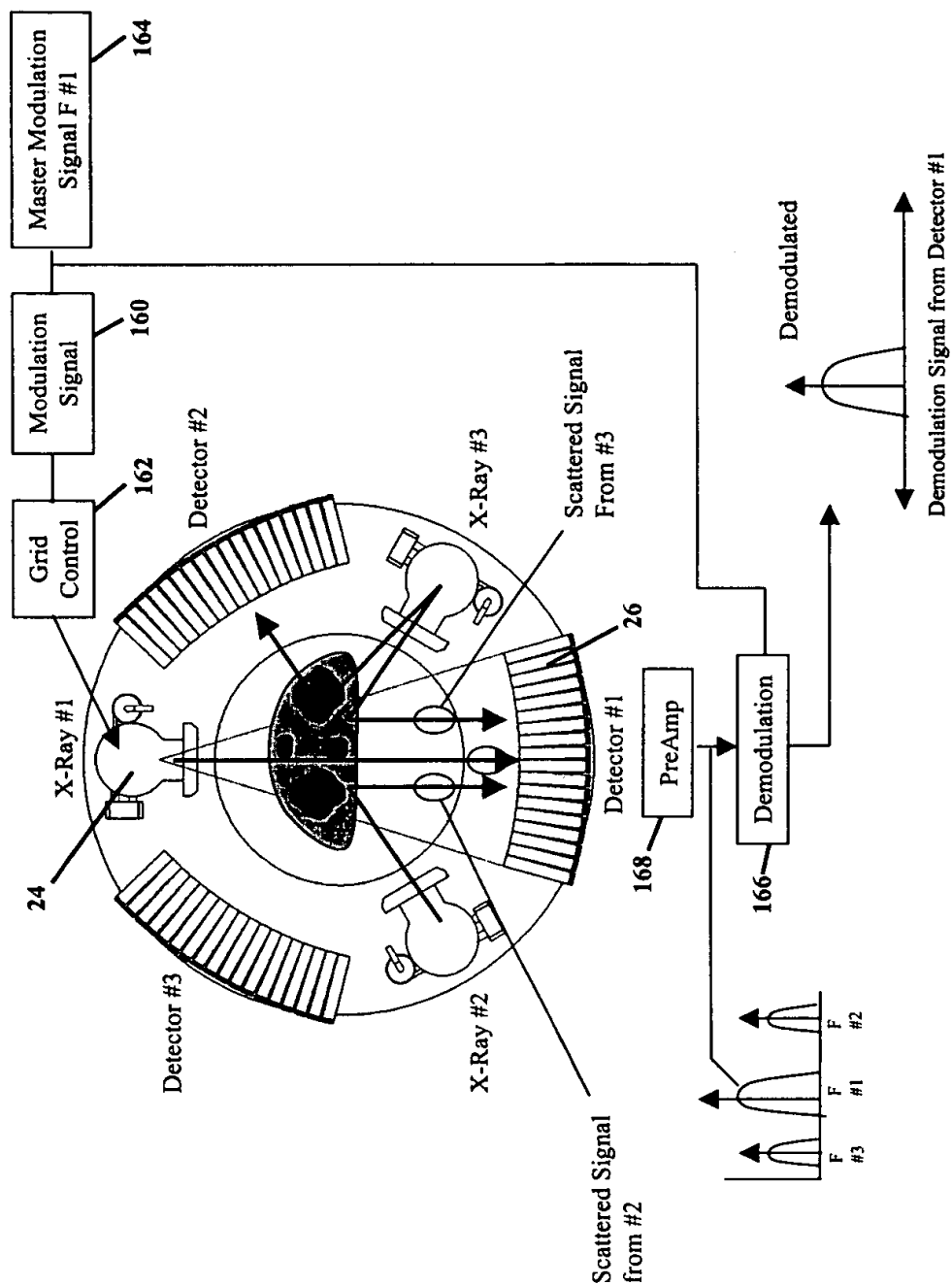
Figure 22

Step and Shoot VCT Imaging

26

26

X-ray Focal
Spot

Scan 1
Scan 2
Scan 3
Scan 4
Scan 5
Scan 6
Scan 7
Scan 8

**Multiple 360 degree
Rotations Stepping
Down the "Z-axis"**

Z -Axis

Figure 23

Spiral 3D X-Ray, DAQ and VCT for Cone Beam Reconstruction

FIG. 24a

Spiral Path with Traverse and Pitch

FIG. 24b

FIG. 24c
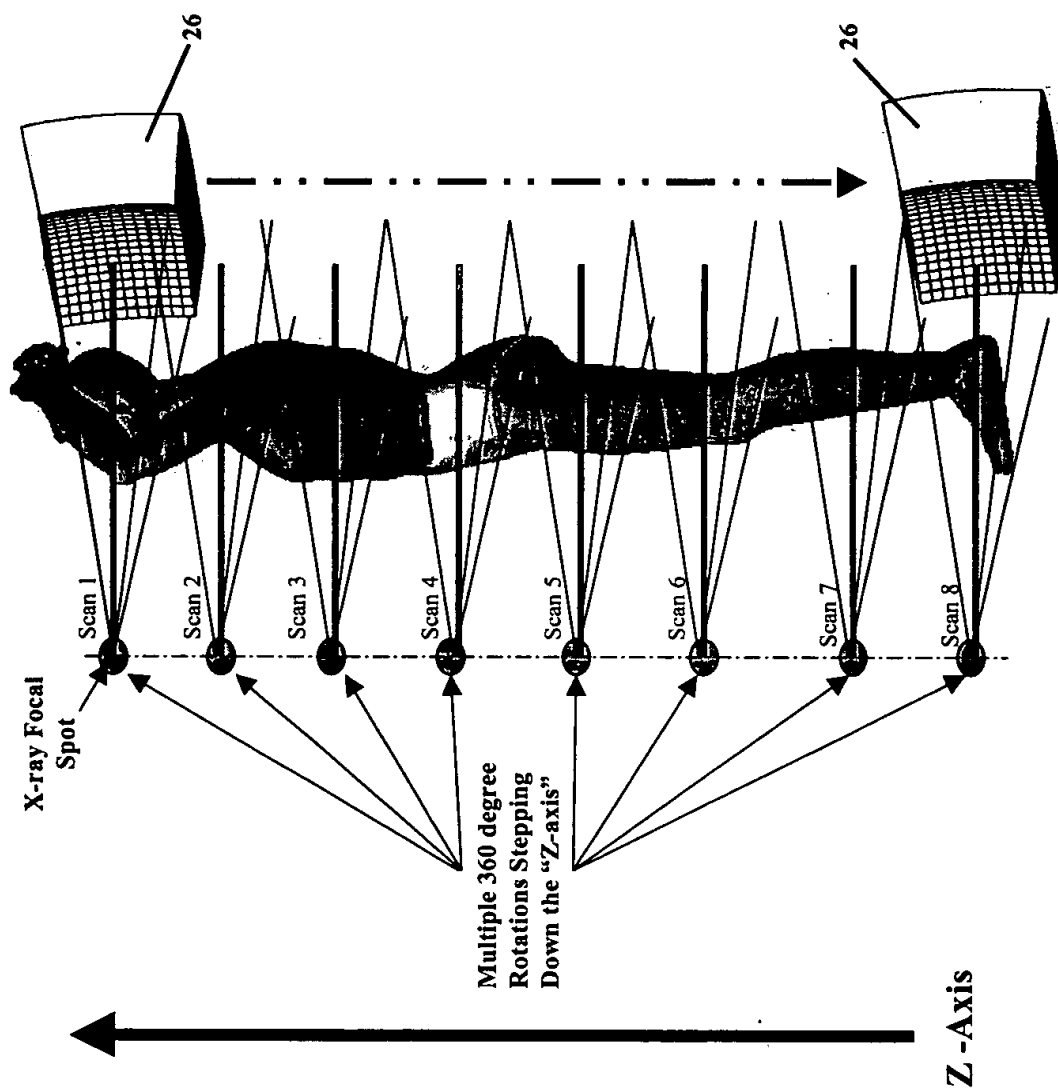
Figure 24

Spiral VCT with Multiple Heads

Detector

Virtual Detector

H_s

W_s

H_s

W_s

172

Source Point

Detector Projection to Scan Center

FIG. 25c

Redundant or Unused Data for 3D Recon

Desired Data for 3D Recon

Redundant or unused Data for 3D Recon

172

Virtual Detector Sampling Region

FIG. 25d

Reconstruction Cylinder

170

26

0°

X-Ray #2

24

X-Ray #1

26

26

180°

X-Ray #3

FIG. 25a

Head 3
Head 2
Head 1
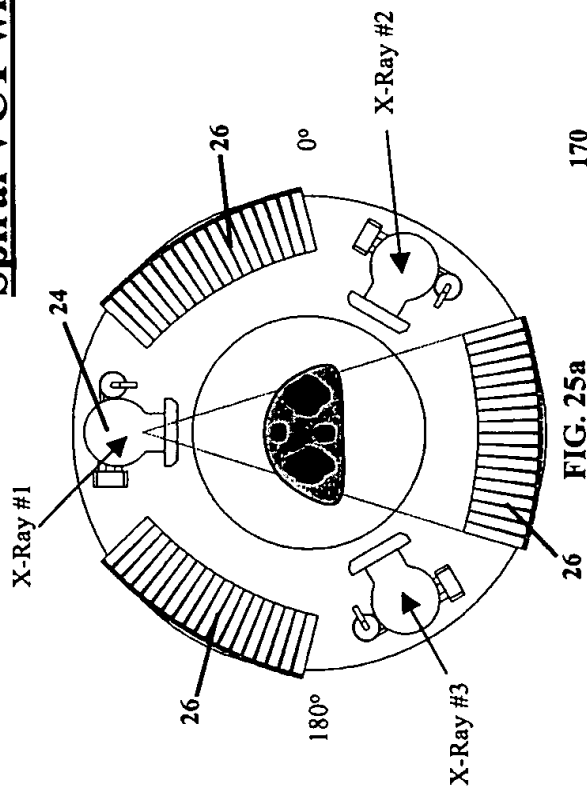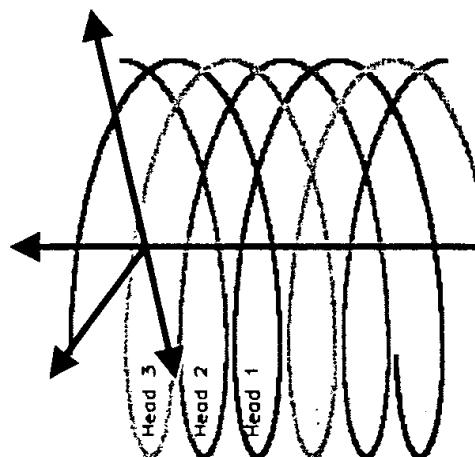
Spiral Path with 3 Heads with respective Central Rays on Reconstruction Cylinder

FIG. 25b

Figure 25

Cone Beam Slant Source Collimation for Spiral VCT Imaging

X-ray Focal Spot

Slant Spiral Collimator

Slant Cone Beam for Spiral Scanning

Slant Spiral Collimator Aperture

Redundant Data for 3D Recon

Desired Data Boundary

Cone Beam Slant Source Collimation Rejection Regions

Desired Data for 3D Recon

Redundant Data for 3D Recon

3 Heads

3 Heads
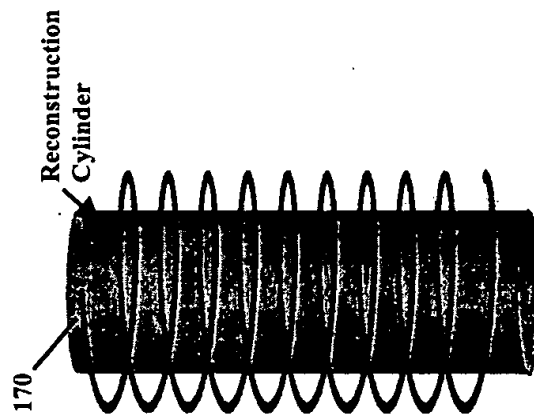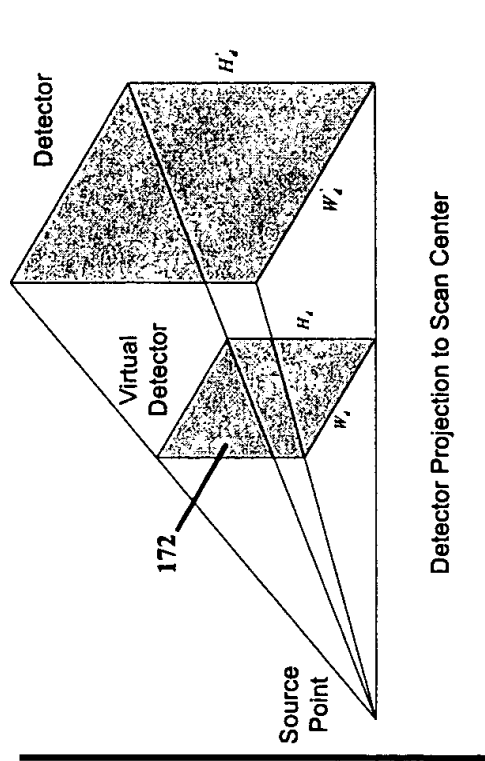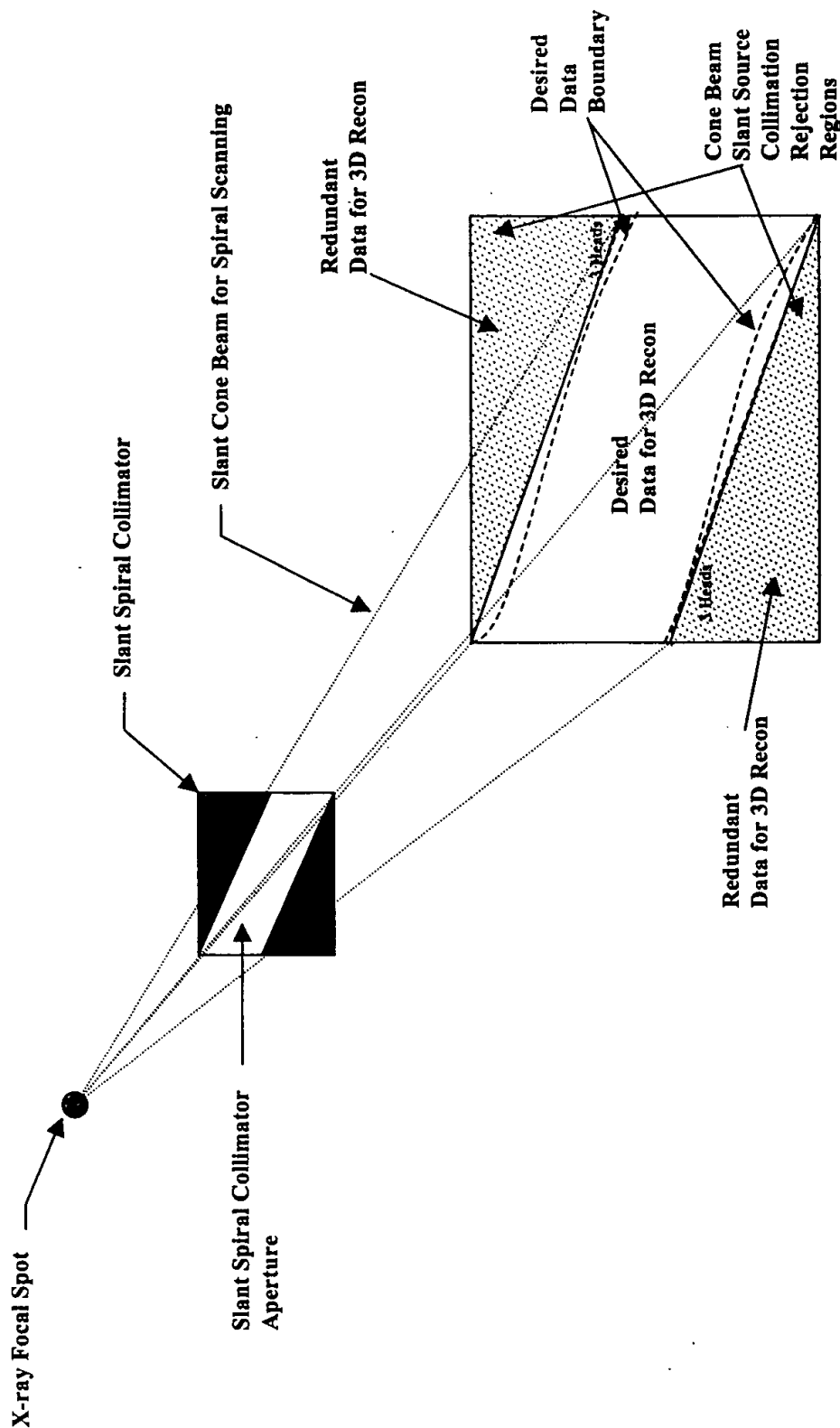
Figure 26

Multi-Plane Planning System Imaging

Rotate Plate Rotating and Snap
Shot Planning Views Taken
While Traversing Patient

26

24

(0,0) → 0 — Anterior — L / R — Ant / Post

(0,0) → 90 — Right — Post / Ant

(0,0) → 180 — Post — R / L

(0,0) → 270 — Left — Ant / Post

Virtual Plane 0°

(0,0)

VP @ 90°

(0,0)

Patient

Ant — R — Post — L

VP @ 180°

(0,0)

VP @/ 270°

(0,0)
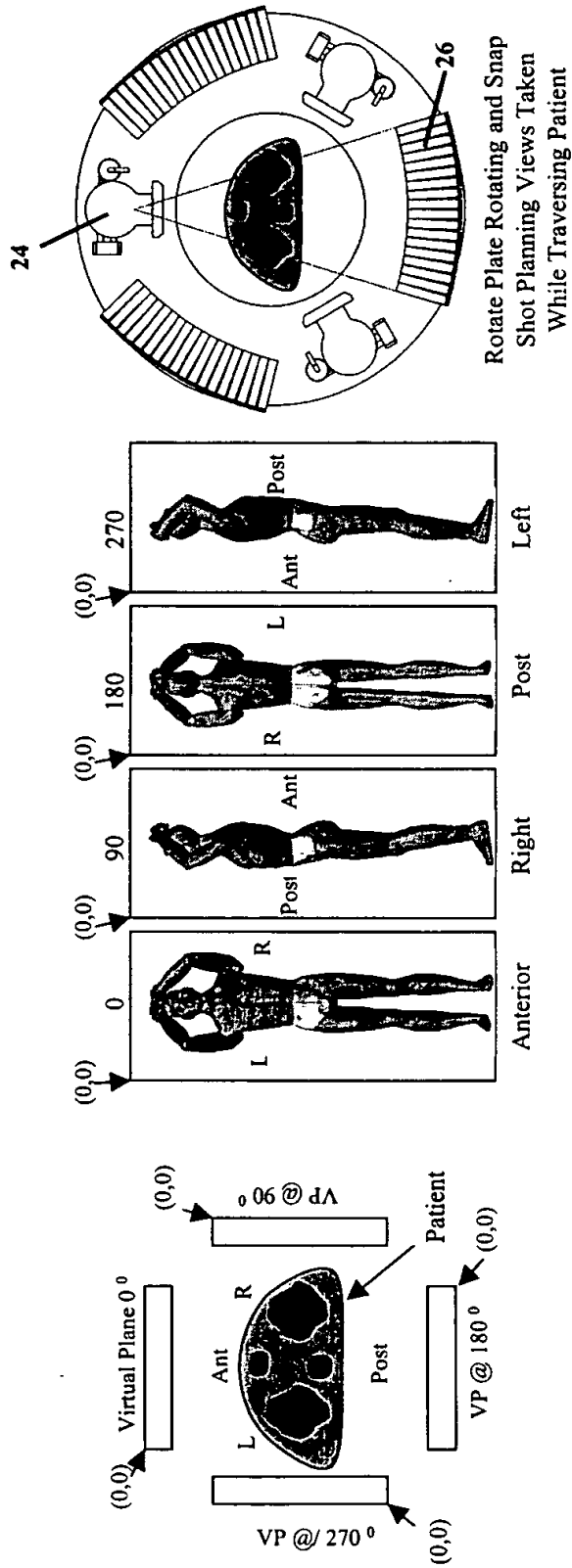
Figure 27

Whole Body Dose Control From Planning System

Normalization Based Upon Minimum Intensity through Patient

90 Degrees

Cone Fan Angle

Intensity

0 Degrees

Cone Fan Angle

Intensity

FIG. 28a

0 Degrees — Cone Fan Angle — Intensity

90 Degrees — Cone Fan Angle — Intensity

180 Degrees — Cone Fan Angle — Intensity

270 Degrees — Cone Fan Angle — Intensity

FIG. 28b

Figure 28

Dynamic Timing Control

Protocol of Scan Procedure

Power Contrast Injector

Foot Exposure Contrast

Monitor of contrast Levels for Triggering of Image Acquisition.

Dynamic Timing Control System — 46

Gating Control System — 48

X-Ray Control — 52

DAQ — 50

Motion Control System — 54

Figure 29

Retrospective Gated Imaging System

GATING CONTROL SYSTEM

Gated Acquisition System — 182

View Angle Window Sorter — 184

RECONSTRUCTION SYSTEM

180

Virtual View Interpolation And Missing View Extrapolation — 186

3D Recon FBP — 188

3D OSEM Recon — 190

48

62

Gating Window on View Angle Plot and EKG Wave Form

EKG

time

View Collection Enabled

View Angle (degrees)

time
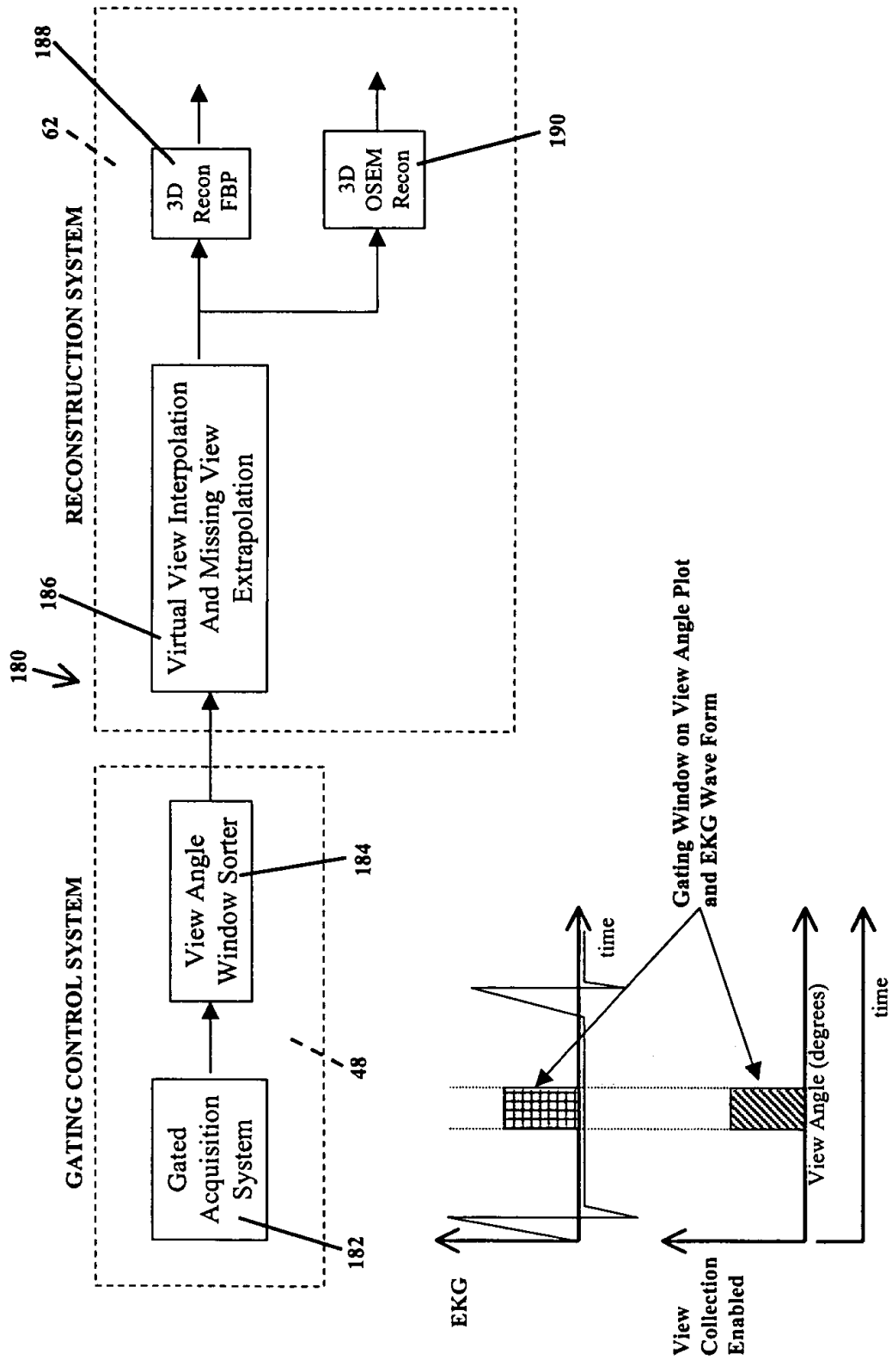
Figure 30

Prospective Gating Control System with Cardiac EKG

Desired and Gating Window

Systole

Diastole

EKG

Heart Rate: 60 bpm

EKG

Physiological Breath Hold Gate Physiological Respiratory

Gating Algorithm

Historical Gating Control Information

48

Gating Control

Operator Go command or Remote Foot Switch

Traverse Position

Traverse Speed

Rotor Position

Rotor Speed

Detector Sampling Control

X-ray on Control
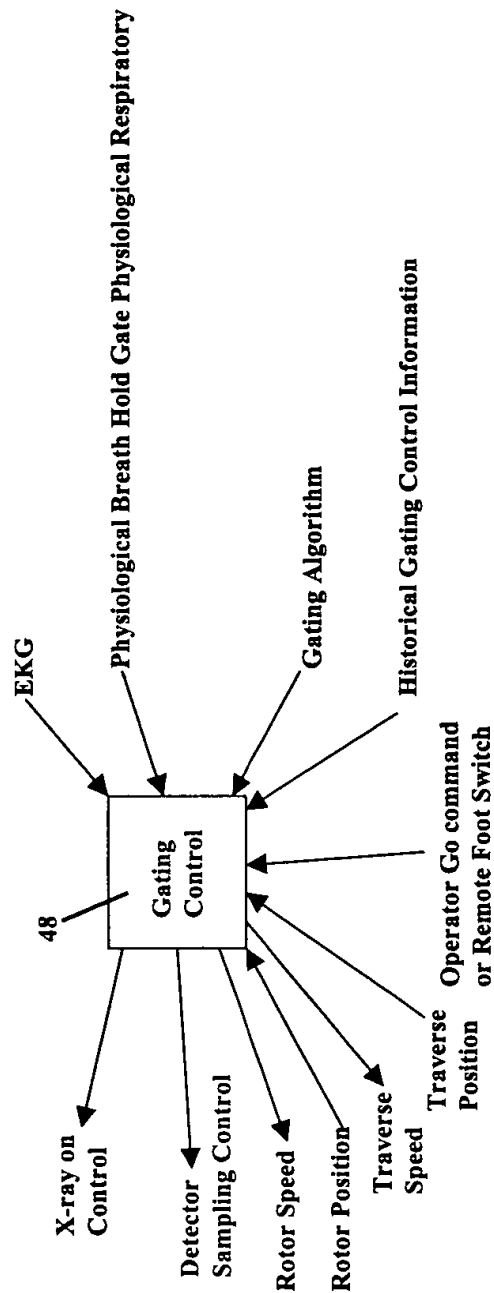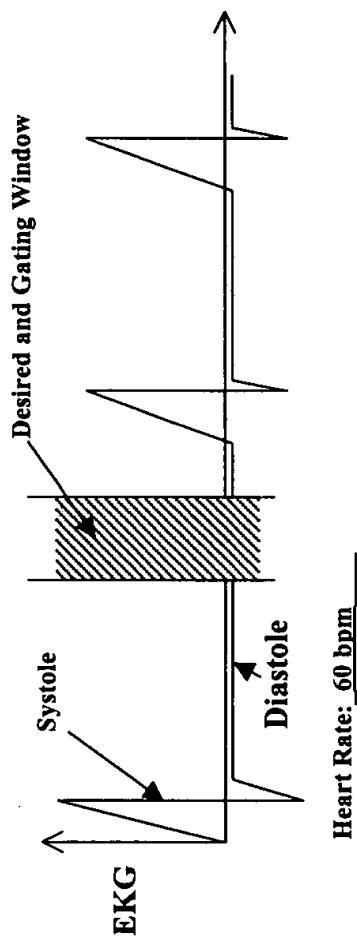
Figure 31

Prospective and Retrospective Gated DAQ and Reconstruction Imaging

Prospective Gating Control

FIG. 32a

FIG. 32b

Rotational Angle

Gate Time for 1 VCT Image Volume

time

Desired Gating Window

twin

Systole

Diastole

t

Retrospective Gating Control

FIG. 32c

FIG. 32d

Beat Cycle

1 2 3 4 5 6

View Angle

0°

360°

1
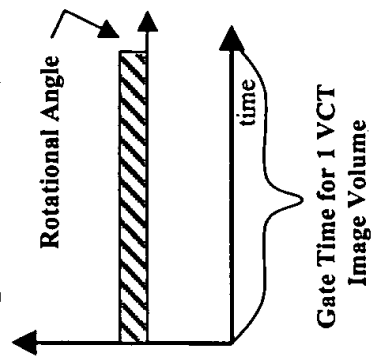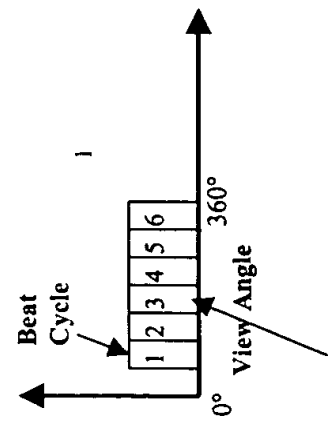
Multiple cardiac cycles to fill needed Views. Collect all views in (n) cycles of Heart.

Desired Gating Window

Systole

Diastole
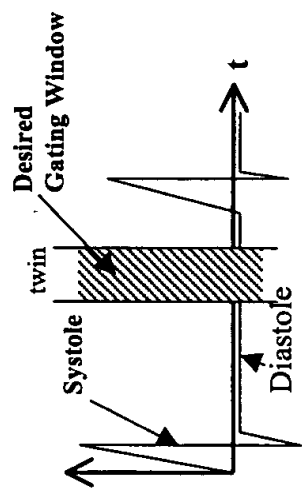
Multi Cycle – Contiguous

FIG. 32e

Gap of Missing Data

Overlapped Data

1 2 3 4 5 6

Δt

Δt

Δt

Δt
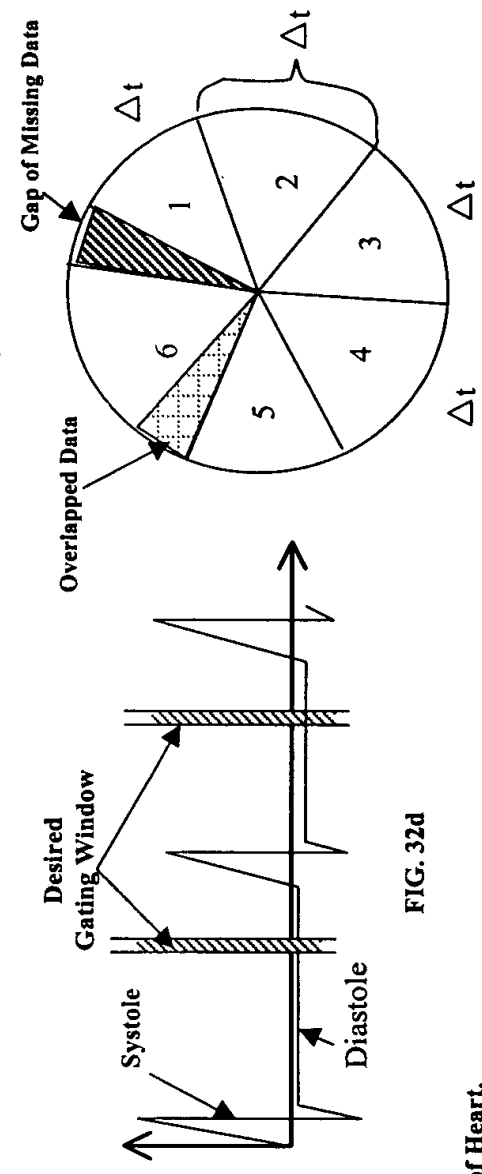
Figure 32

Gated DAQ and Reconstruction for Retrospective Cine' Dynamic

Cardiac Imaging

Derived ~ 50ms Windows

1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6

C1   C2   C3   C4   C5

FIG. 33a

Views or θ/sec = 360° / .25 = 1440 °/sec
½° View Spacing = 2880 views/sec

Desired Window: 50ms
In One Window: 2880 x 5 x 10^{-2} = 144 views
                  72 degrees

3 cycles for 180°   3 x 72 = 216°
5 cycles for 360°

5 Sectors of Pie Diagram

Average EKG

FIG. 33c

Z axis

R

0°   1 2 3 4 5 6   360°

View Angle (θ)
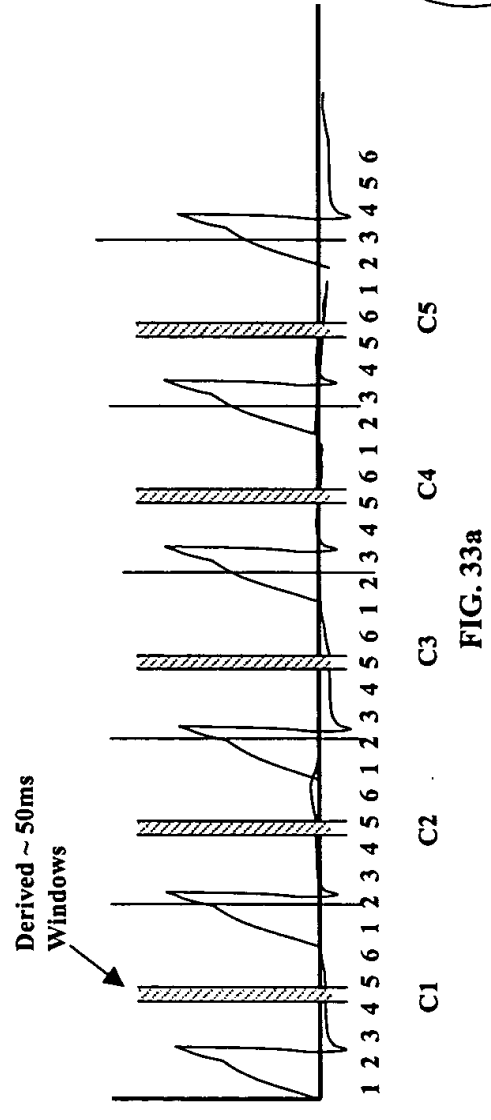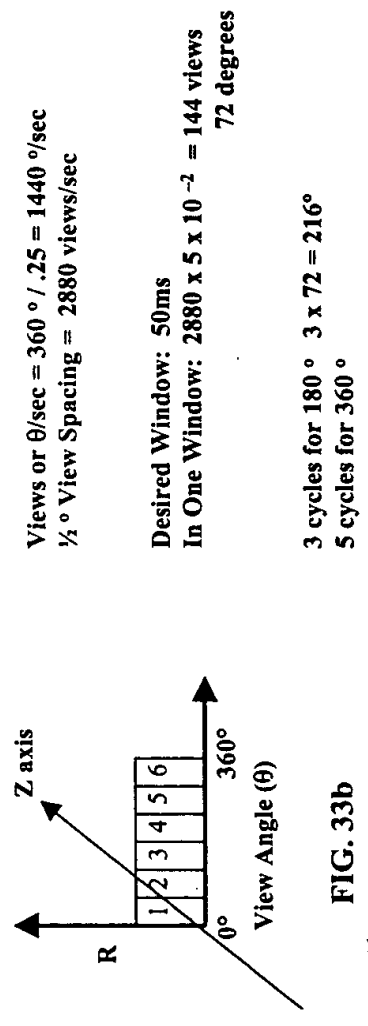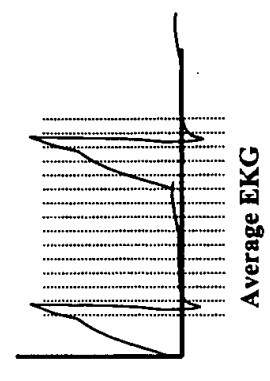
FIG. 33b

Figure 33

PET Transmission, Attenuation & Scatter Correction

VCT Attenuation MAP

**Transmission Attenuation
Map at 511 KEV Energy Level from VCT Images**

PET Attenuation Correction
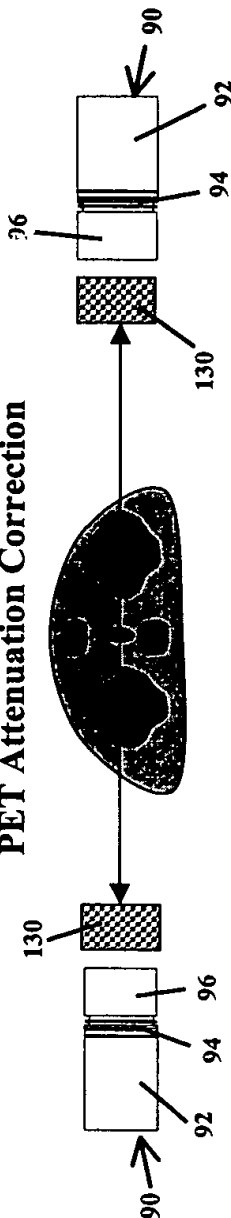
**Correction Map for PET New Corrected PET
Projections for OSEM Recon.**

PET Scatter Correction

Scatter

LOR
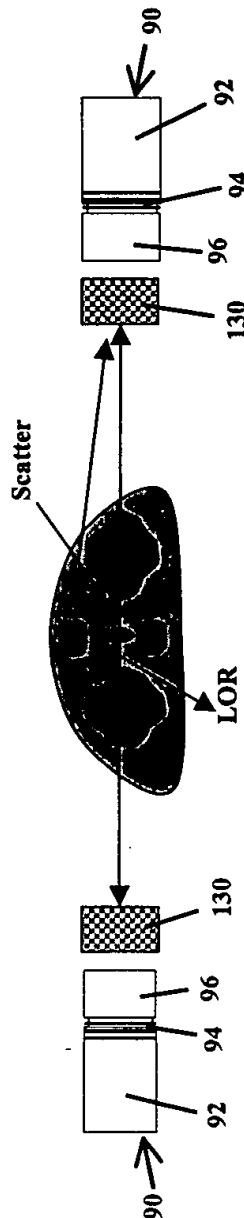
**Scatter Correction from VCT Images and
Count Rates on a Projection View Basis**

Figure 34

NM/SPECT Transmission, Attenuation & Scatter Correction

VCT Attenuation MAP

Transmission Attenuation
Map at NM/SPECT Energy Levels from VCT Images

NM/SPECT Attenuation Correction
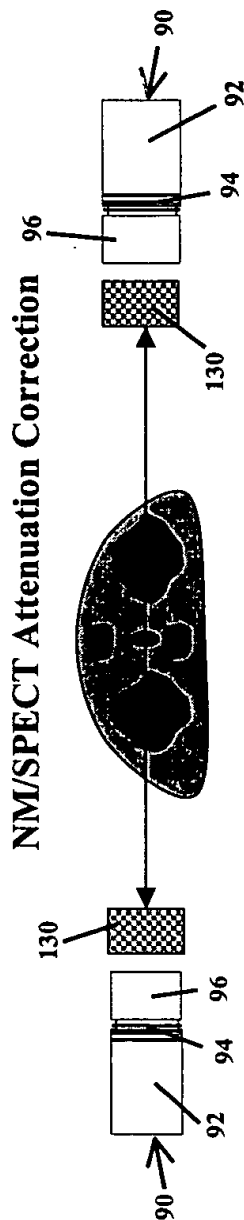
Correction Map for NM/SPECT New Corrected
SPECT Projections for OSEM Recon.

Scatter Correction
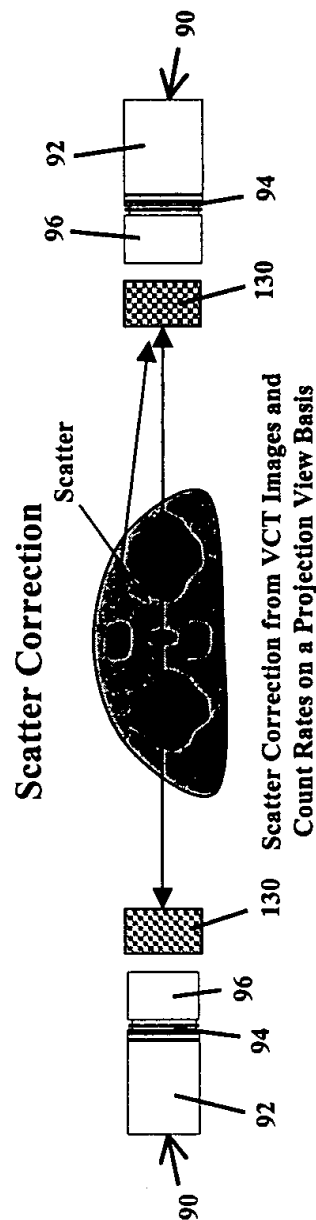
Scatter

Scatter Correction from VCT Images and
Count Rates on a Projection View Basis

Figure 35

Patient Fused Multi-Modality Imaging and Analysis System

IMAGE ANALYSIS SYSTEM

Computer Aided Diagnosis

Fusion

Metabolic and Morphological Info

Disease Process Model

Anatomy Image

PET Function FDG

SPECT Function

Gold History Data Base

16

MULTI MODELITY IMAGING SYSTEM

VCT
DR
PET
SPECT
IMAGING

14

Anatomical

Physiological

Molecular

Disease Process

Organ System
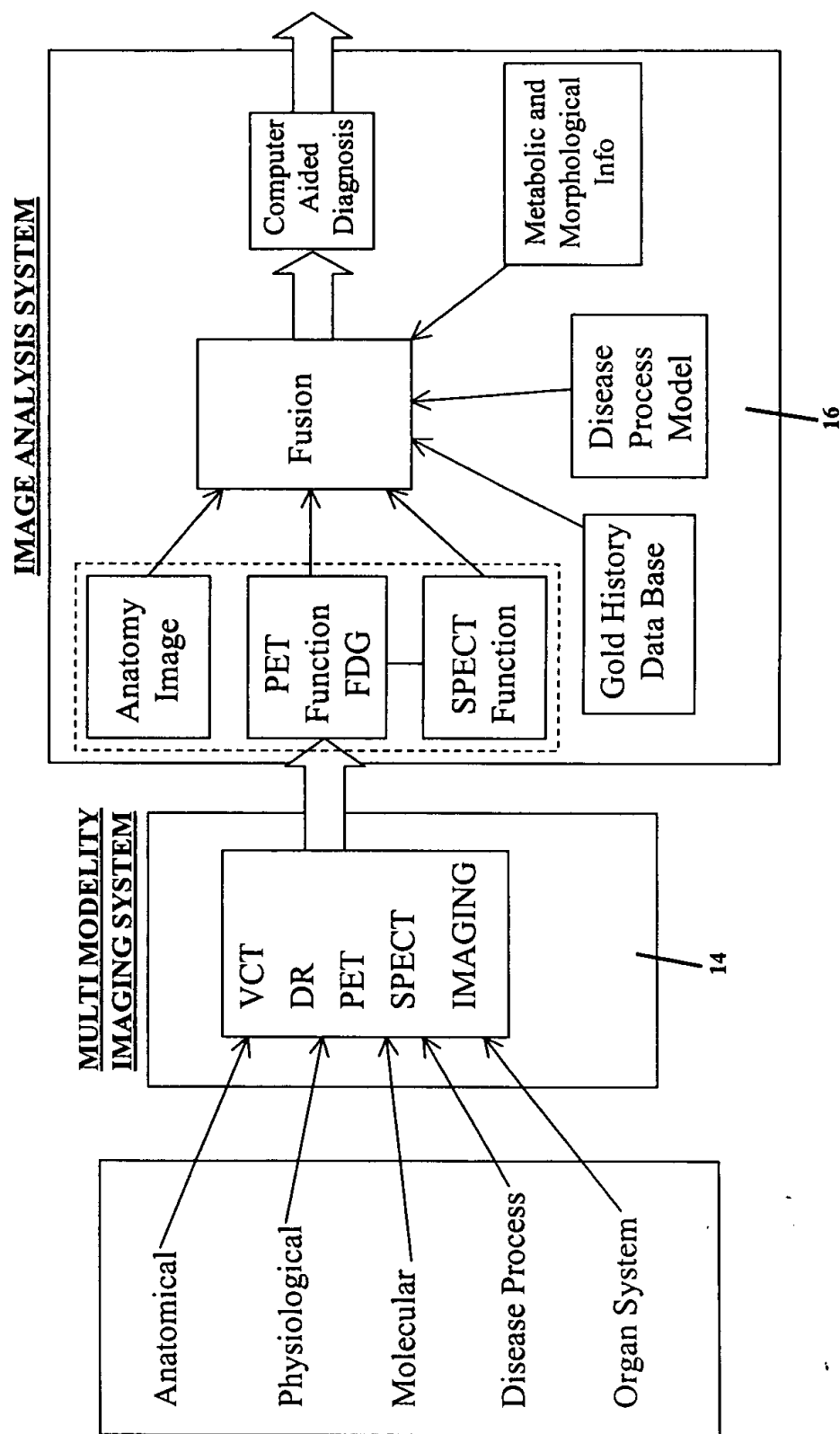
Figure 36

Interventional Image Control System

Figure 37

Multi-Modality Imaging with Independent X-Ray VCT, PET, and NM/SPECT Image Acquisition System

212

130

218

210

98

216

30

20

214

24

26

28

90

22
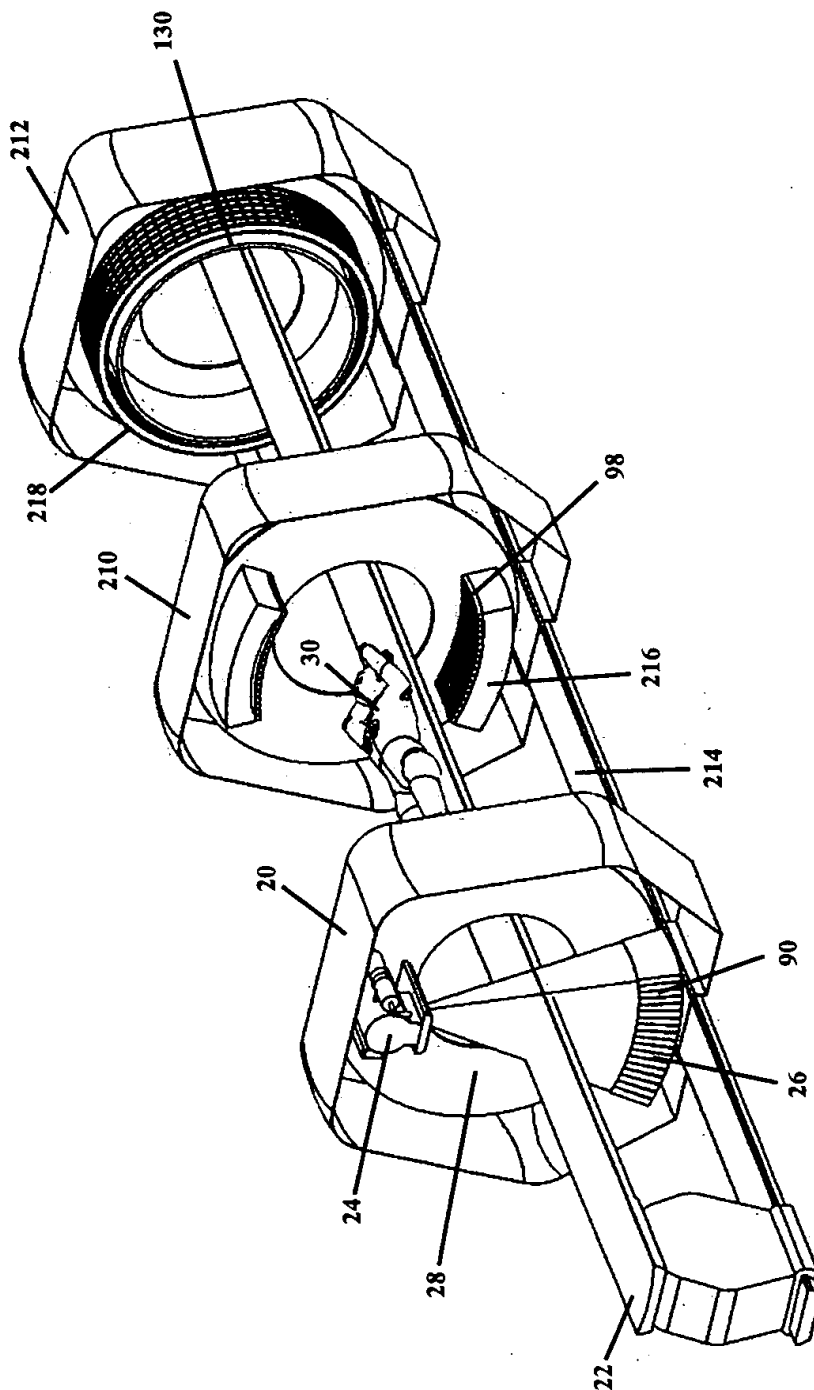
Figure 38

Multi-Modality Imaging with Independent X-Ray Single Head VCT, PET, and NM/SPECT Image Acquisition System

Figure 39

Multi-Modality Imaging with Independent X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System

Figure 40

Multi-Modality Imaging System with Stationary
Focused 2D Curved Detector for VCT, PET and NM/SPECT Imaging

Figure 41

Multi-Modality Imaging with Common Gantry and Independent X-Ray VCT, PET, and NM/SPECT Image Acquisition System

Figure 42

Multi-Modality Imaging with Common Gantry and Independent X-Ray Single Head VCT, PET, and NM/SPECT Image Acquisition System
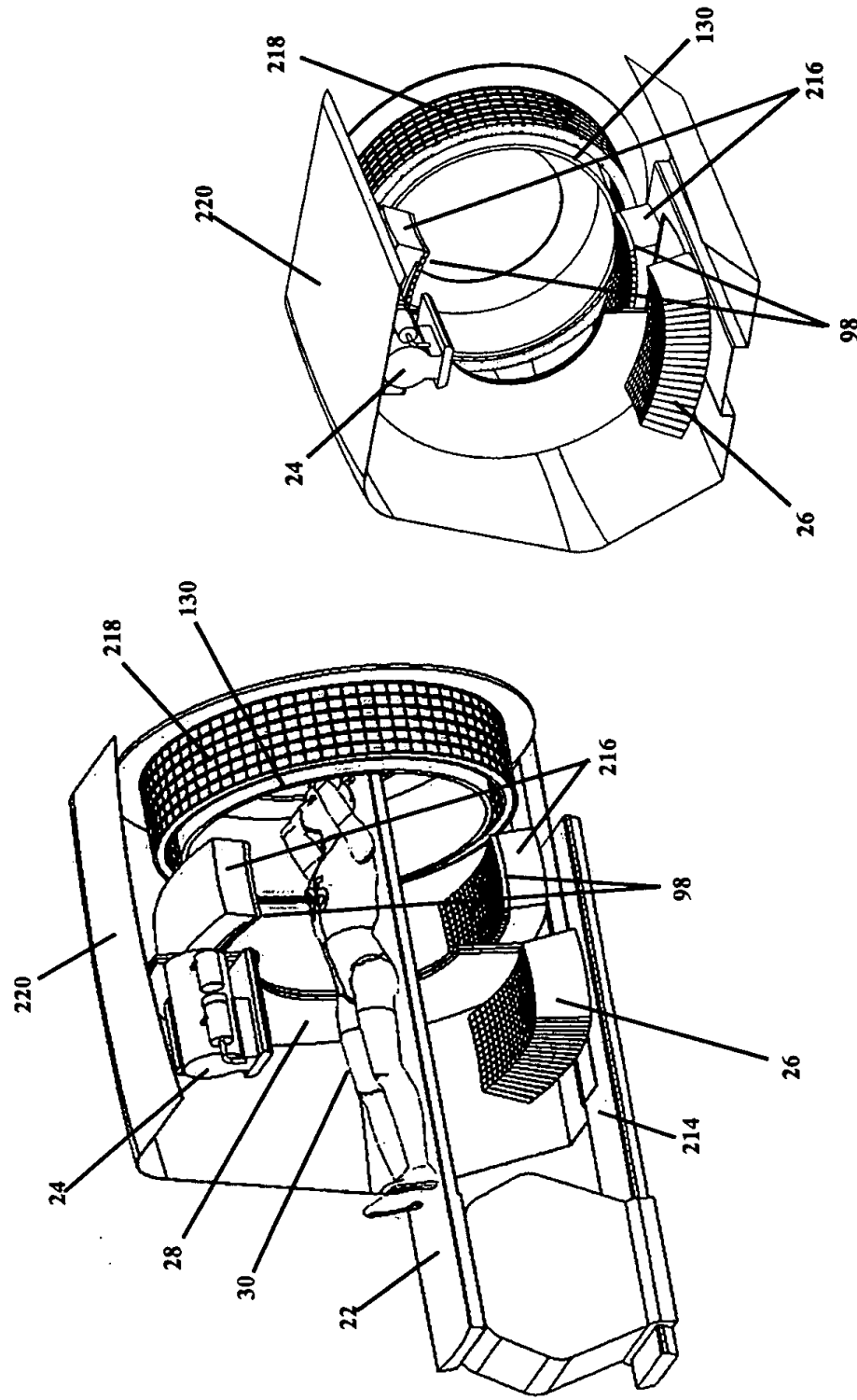
Figure 43

Multi-Modality Imaging with Common Gantry and Independent X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System

Figure 44

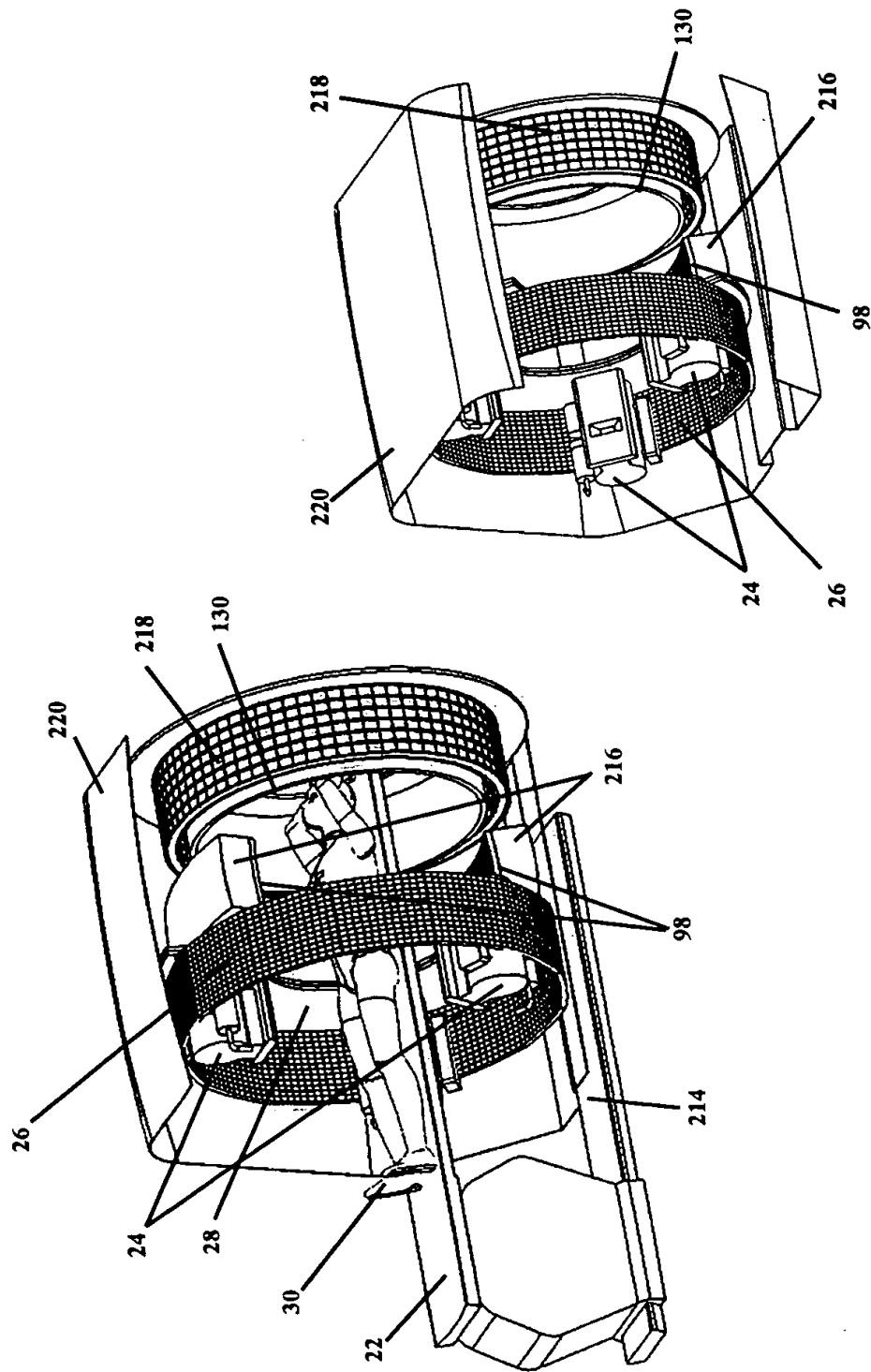## Multi-Modality Imaging with Common Gantry and Independent Single X-Ray 4th Generation VCT, PET, and NM/SPECT Image Acquisition System
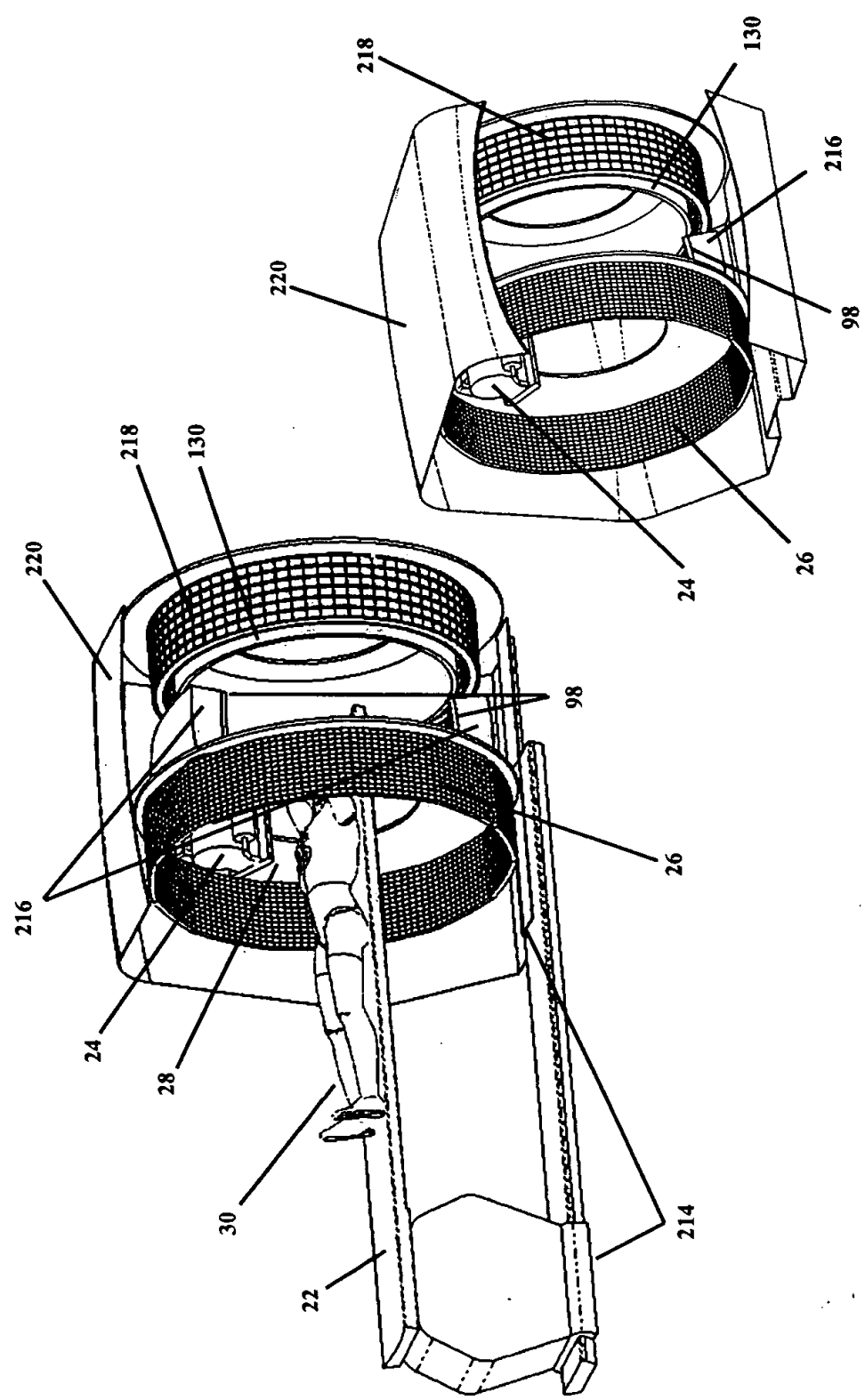

Figure 45